DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

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COMPUTER PROGRAM FOR PERFORMANCE AND SIZING ANALYSIS OF COMPACT COUNTER-FLOW PLATE-FIN HEAT EXCHANGERS

by

Jon C. Ness

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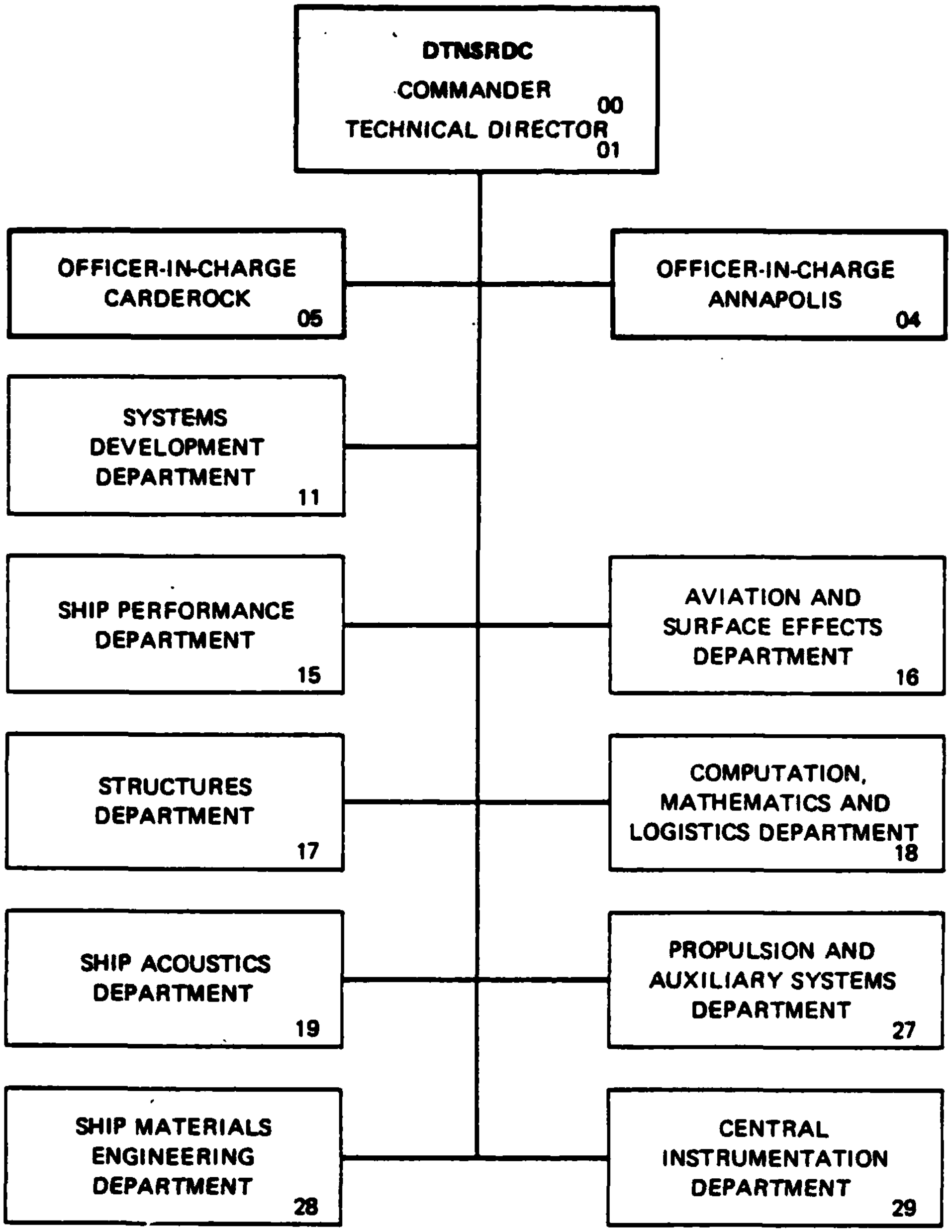

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This report presents a computer program for preliminary design analysis of counter-flow, compact, plate-fin heat exchangers. The program method is based on the effectiveness-NTU relationship analysis. The heat exchanger design begins with assumptions for counter-flow length, total frontal flow area and core matrix fin geometry. Using these constraints, the program proceeds to calculate the resulting effectiveness and pressure drop based on specified air-side and gas-side conditions. Input design requirements include

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selected air-side and gas-side fin types; the pressures, temperatures, and mass flows of the air and gas streams; fuel-air ratio; as well as, the maximum air-side inlet header velocity. Heat exchanger designs may be generated based on four different fin types (i.e., plain, louvered, strip/offset or wavy fins) over a varied number of core dimensions. Program output includes inlet and exit conditions on air and gas sides, effectiveness, fin characteristics, core length and volume, total frontal flow area, pressure drops, overall enclosure height, number of transfer units, overall weight, and air-side header diameters and velocities. This report presents the analysis method, description of input and output with sample cases, and a program listing.

TABLE OF CONTENTS

LIST OF FIGURES

SYMBOLS

A - Exchanger total heat transfer area on one side, ft^2

A_c - Exchanger minimum free-flow area, ft^2

A_{fr} - Exchanger total frontal area, ft^2

a - Plate thickness, in

b - Plate spacing, in

C - Flow stream capacity rate, BTU/(hr °F)

C_c - Jet contraction-area ratio, dimensionless

C_r - Capacity rate ratio

c_p - Specific heat at constant pressure, BTU/(lb_m °F)

D - Air-side header diameter, ft

f - Mean friction factor, (Equation 32)

far - Fuel-air ratio

G - Exchanger flow-stream mass velocity, lb_m/(hr ft^2)

g_c - Proportionality factor in Newton's second law, lb_m ft/(lb_f sec^2)

h - Unit conductance for thermal-convection heat transfer, BTU/(hr ft^2 °F)

j - Colburn factor = $N_{ST} N_{PR}{}^{2/3}$

K_b^* - Bend loss coefficient

K_c - Contraction loss coefficient for flow at heat exchanger entrance, dimensionless

K_d - Momentum flux correction factor, dimensionless

K_e - Expansion loss coefficient for flow at heat exchanger exit, dimensionless

K_1 - Constant used in Equation 14

K_2 - Constant used in Equation 15

k - Unit thermal conductivity, BTU/(hr ft^2 °F/ft)

L - Heat exchanger counter-flow length, ft

L_g - Gas-side header length, ft

L_n - Heat exchanger non-flow length, ft

ℓ - Fin length from root to center, ft

M - Molecular weight

m - A fin effectiveness parameter $(2h/k\delta)^{1/2}$

N_{PR} - Prandlt number, dimensionless

N_R - Reynolds number, dimensionless

N_{ST} - Stanton number, dimensionless

NTU - Number of transfer units

P - Power

P_f - Fractional Power

p - Pressure, lb_f/in^2

q - Dynamic velocity, lb_f/ft^2

R_u - Universal gas constant, ft lb_f/(lb mol)(°R)

r_h - Hydraulic radius = A_cL/A

T - Temperature, °F or °R

U - Unit overall thermal conductance, BTU/(hr ft^2 °F)

$\forall$ - Volume, ft^3

V - Velocity, ft/sec

v - Specific volume, ft^3/lb_m

W_a - Weight of air-side fins and plates, lb_f

W_{ENCL} - Weight of enclosure, lb_f

W_g - Weight of gas-side fins and plates, lb_f

W_{HD} - Weight of headers, lb_f

W_T - Total weight of heat exchanger, lb_f

w - Mass flow rate, lb_m/sec

α - Ratio of total transfer area on one side of the exchanger to total volume of the exchanger, ft^2/ft^3

β - Ratio of total heat transfer area on one side of a plate-fin heat exchanger to the volume between the plates on that side, ft^2/ft^3

Δ - Denotes a difference between values of the same parameter

δ - Fin thickness, in

ϵ - Heat exchanger effectiveness, dimensionless

η_f - Fin effectiveness, dimensionless

η_o - Total surface effectiveness, dimensionless

σ - Ratio of free flow area to frontal area

μ - Viscosity coefficient, lb_m/(hr ft)

π - Constant = 3.1416

ρ - Density, lb_m/ft^3

ρ_c - Density of core, lb_m/ft^3

ρ_m - Density of material, lb_m/ft^3

ρ_n - Density of material per unit area, lb_m/ft^2

ψ_f - Fin weight factor

ψ_p - Plate weight factor

SUBSCRIPT

a - air-side

av - average

b - bend

c - core

g - gas-side

i - inlet

m - mean value

max - maximum value

min - minimum value

o - outlet

t - total

1 - entrance condition

2 - exit condition

3 - compressor exit condition

4 - turbine inlet condition

5 - turbine outlet condition

6 - recuperator outlet condition

LIST OF ABBREVIATIONS

BTU	-	British thermal unit
CDC	-	Control Data Corporation
°F	-	Degrees Fahrenheit
ft	-	Feet
hr	-	Hour
in	-	Inch
lb_f	-	Pounds force
lb_m	-	Pounds mass
NTU	-	Number of Transfer Units
psia	-	Pound force per square inch absolute
°R	-	Degrees Rankine
sec	-	Second

ABSTRACT

This report presents a computer program for preliminary design analysis of counter-flow, compact, plate-fin heat exchangers. The program method is based on the effectiveness-NTU relationship analysis. The heat exchanger design begins with assumptions for counter-flow length, total frontal flow area and core matrix fin geometry. Using these constraints, the program proceeds to calculate the resulting effectiveness and pressure drop based on specified air-side and gas-side conditions. Input design requirements include selected air-side and gas-side fin types; the pressures, temperatures, and mass flows of the air and gas streams; fuel-air ratio; as well as, the maximum air-side inlet header velocity. Heat exchanger designs may be generated based on four different fin types (i.e., plain, louvered, strip/offset or wavy fins) over a varied number of core dimensions. Program output includes inlet and exit conditions on air and gas sides, effectiveness, fin characteristics, core length and volume, total frontal flow area, pressure drops, overall enclosure height, number of transfer units, overall weight, and air-side header diameters and velocities. This report presents the analysis method, description of input and output with sample cases, and a program listing.

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INTRODUCTION

Preliminary design analysis of compact heat exchangers for gas turbine engine applications involves repetitious calculations varying design and performance over a range of conditions. In order to determine "an optimum" design, thousands of these calculations must be completed. Design accuracy and details which are necessary in manufacturing a heat exchanger are not necessary for this type of preliminary design analysis. General and approximate procedures are sufficient to yield the desired design and performance characteristics.

This report presents a computer program for preliminary design analysis of counterflow, compact, plate-fin heat exchangers. The computer program is based on the effectiveness-NTU relationship, [1]. The heat exchanger design begins with assumptions for counter-flow length, total frontal flow area and core matrix fin geometry. Using these contraints, the program proceeds to calculate the resulting effectiveness and pressure drop based on specified air-side and gas-side inlet conditions. Input requirements are air-side and gas-side fin types; the pressures, temperatures, and mass flows, of the air and gas streams; fuel-air ratio; as well as, the air-side inlet header velocity. The program gives the designer the capability to select from four different fin-types (i.e., plain, louvered, strip/offset, and wavy) with a variety of surfaces (i.e., fins/in and fin heights) for each fin type. All the necessary data and characterisitics for the fin types are located in reference 1. The input data includes assumed values of core counter-flow length and frontal area to be used in the computations described below. Output consists of all input requirements, as well as, calculated parameters including core volume, pressure drops, overall enclosure height, air and gas exit temperatures and pressures, number of transfer units, heat exchanger effectiveness, overall weight, and air-side header exit diameter and velocity.

A complete description of input and output variables, a FORTRAN IV program listing, and discussion of the analysis method are included in the report. Also, included are examples for using the program, and illustrations of output.

METHOD OF ANALYSIS

In sizing heat exchangers there are two parameters which affect size and shape. These parameters are effectiveness ε, and pressure drop Δp.

The objective of using a heat exchanger as a regenerator in gas turbines is to raise the compressor exit temperature using the waste heat from exhaust gases; therefore, increasing thermal efficiency. Raising the air temperature in a regenerator to that of the entering gas temperature would constitute a perfect heat exchanger. How close the air-side exit temperature reaches the entering gas-side temperature defines effectiveness. In order to define heat exchanger effectiveness, a capacity rate is used. The capacity rate is the mass flow rate times the heat capacity. For regeneration in gas turbine engine applications, the capacity rate is slightly lower on the air-side then on the gas-side due to compressor bleeds lowering air-side mass flow rate, combustion products increasing gas-side mass flow rate, and increasing heat capacity as temperature rises. Effectiveness is defined as [1],

$$\varepsilon = \frac{T_{a_o} - T_{a_i}}{T_{g_i} - T_{a_i}} \quad \text{(1a)}$$

Alternatively,

$$\varepsilon = \left(\frac{C_g}{C_a}\right) \frac{T_{g_i} - T_{g_o}}{T_{g_i} - T_{a_i}} \quad \text{(1b)}$$

T_{a_o} = air-side exit temperature
T_{a_i} = air-side entering temperature
T_{g_o} = gas-side exit temperature
T_{g_i} = gas-side entering temperature
C = capacity rate.

Heat transfer can be related to a nondimensional parameter, known as the number of transfer units (NTU), in terms of [1],

$$NTU = \frac{A\ U_{av}}{C_{min}} \quad \text{(2)}$$

where,

A = heat transfer area, ft^2

U_{av} = average overall heat transfer coefficient, BTU/(hr ft^2 °F)

C_{min} = minimum capacity rate, BTU/(hr °F)

For a counterflow heat exchanger, which this computer program is based upon, the relationship of effectiveness to NTU is [1],

$$\varepsilon = \frac{1 - e^{-NTU\left(1 - C_{min}/C_{max}\right)}}{1 - \frac{C_{min}}{C_{max}} e^{-NTU\left(1 - C_{min}/C_{max}\right)}} . \tag{3}$$

Equations for other configurations (i.e., crossflow, parallel flow, etc.) can be found in reference 1.

Pressure drop (Δp) in a heat exchanger can adversely affect the performance of the heat exchanger and the specific power of the gas turbine. Pressure drop can be made nondimensional by dividing the change in pressure by the absolute pressure before the pressure drop occurs. This nondimensional pressure drop can be related to a fractional pressure drop, which is directly related to a power loss in the gas turbine, regardless of whether the Δp occurs on the air-side or gas-side, [2]. The above mentioned statement may be made clearer with the aid of figure 1 and the following derivations: At a given turbine inlet temperature, power is proportional to the pressure ratio across the turbine (p_4/p_5). Assume that an overall pressure ratio (p_3/p_6) can be related to p_4/p_5 by considering the pressure losses across the heat exchanger and burner (Δp_a = air-side drop, Δp_g = gas-side drop, and Δp_b = burner drop); then the recuperated turbine pressure ratio can be written in terms of the overall pressure ratio.

$$\frac{p_4}{p_5} = \frac{p_3 - \Delta p_b - \Delta p_a}{p_6 + \Delta p_g} = \frac{p_3}{p_6} \frac{\left(1 - \frac{\Delta p_b}{p_3} - \frac{\Delta p_a}{p_3}\right)}{\left(1 + \frac{\Delta p_g}{p_6}\right)} \tag{4}$$

The fractional power loss due to recuperation can be expressed in the following manner for small pressure losses,

$$\frac{\Delta P_f}{P_{old}} = \frac{P_{new} - P_{old}}{P_{old}} = \frac{P_{new}}{P_{old}} - 1 \tag{5}$$

where,

$$P_{new} = \frac{p_3}{p_6} \frac{\left(1 - \frac{\Delta p_b}{p_3} - \frac{\Delta p_a}{p_3}\right)}{\left(1 + \frac{\Delta p_g}{p_6}\right)} \tag{6a}$$

$$P_{old} = \frac{p_3}{p_6} \left(1 - \frac{\Delta p_b}{p_3}\right) \quad (\text{since } \Delta p_a = \Delta p_g = 0). \tag{6b}$$

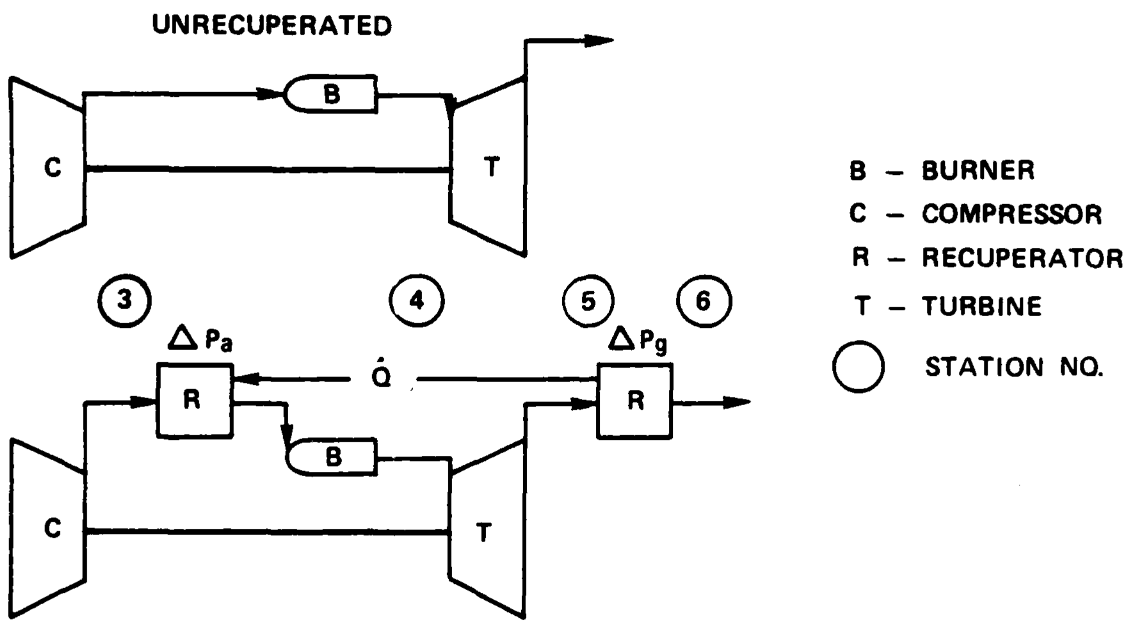

Figure 1 - Simple (Unrecuperated) and Recuperated Gas Turbine Cycles

Substituting in P_{new} and P_{old}, remembering that the pressure drops are small relative to the absolute pressures, and ignoring second order terms, equation (5) becomes,

$$\frac{\Delta P_f}{P_{old}} = \frac{(1 - \frac{\Delta p_b}{p_3} - \frac{\Delta p_a}{p_3})}{(1 + \frac{\Delta p_g}{p_6})(1 - \frac{\Delta p_b}{p_3})} - 1 \approx - (\frac{\Delta p_a}{p_3} + \frac{\Delta p_g}{p_6}) . \qquad (7)$$

Therefore, the fractional power loss due to regeneration is related to the fractional pressure losses across the recuperator by equation (7). Since power losses in the cycle can result from pressure drops in the heat exchanger, it is desirable to keep pressure losses to a minimum. This can be accomplished by choosing fin types that do not create high pressure losses. For example, plain fins instead of strip fins, short flow lengths, or large frontal areas, which may create other problems that are not dealt with in this manual.

As stated earlier, the heat exchanger design begins with assumptions for counter-flow length, total frontal flow area and core matrix fin geometry. Using these constraints, the program proceeds to calculate the resulting effectiveness and pressure drop based on specified air-side and gas-side inlet conditions. The basic procedure is summarized below:

(1) GIVEN: Mass flow rates, inlet pressure, and inlet temperatures on both air and gas sides.

(2) SELECT: Surface characteristics (i.e., fins/in and fin height) both sides

(3) CALCULATE: Heat transfer and free flow areas on both sides, Equations (9) and (11)

(4) DETERMINE: Fluid properties on both sides

(5) CALCULATE: Reynolds number of both sides, Equation (13)

(6) DETERMINE: Stanton number, Colburn factor and friction factor

(7) CALCULATE: Heat transfer coefficient on both sides, Equation (17)

(8) CALCULATE: Fin effectiveness on both sides, Equation (18)

(9) CALCULATE: Surface effectiveness on both sides, Equation (21)

(10) CALCULATE: Overall coefficient of heat transfer based on the air-side area, Equation (22)

(11) CALCULATE: NTU and exchanger effectiveness, Equations (2) and (25)

(12) CALCULATE: Inlet and exit loss coefficients, Equations (34) and (35); and core pressure drop on both sides, Equations (30), (36), (37), and (38)

This procedure requires the following inputs: air flow rate w_a, fuel-air ratio far, air-side fin surface, air-side entering pressure p_{1a}, air-side entering temperature T_{1a}, gas-side fin surface, gas-side entering pressure p_{1g}, gas-side entering temperature T_{1g}, a plate thickness a, and a thermal conductivity k for the fin material and parting plates. By specifying the fin surface, characterisitics accompany the fins, such as, plate spacing b, hydraulic radius r_h, fin thickness δ, ratio of transfer area to volume between plates β, and ratio of fin or extended area to total area are determined. The frontal area A_{fr}, and the heat exchanger core volume $V\!\!\!\!-$ must be specified for the calculations.

HEAT TRANSFER AND FREE-FLOW AREA

The ratio of total transfer area on one side (i.e., air-side, gas-side) of the heat exchanger to the total volume of the exchanger is given by,

$$\alpha_a = \frac{A_a}{V\!\!\!\!-_{total}} = \frac{b_a \beta_a}{b_a + b_g + 2a} \text{, for the air-side,} \tag{8a}$$

and

$$\alpha_g = \frac{A_g}{V\!\!\!\!-_{total}} = \frac{b_g \beta_g}{b_g + b_a + 2a} \text{, for the gas-side.} \tag{8b}$$

Rearrangement of Equation (8a) or (8b) gives the total heat transfer area on one side,

$$A = \alpha V\!\!\!\!-_{total} \cdot \tag{9}$$

The ratio of free-flow area to frontal area is defined as,

$$\sigma = \frac{A_c}{A_{fr}} = \alpha\, r_h \ . \tag{10}$$

Rearrangement of Equation (10) give the free-flow area on one side as

$$A_c = \sigma\, A_{fr} \ . \tag{11}$$

FLUID PROPERTIES

An initial value for heat exchanger effectiveness is assumed only to estimate an average bulk temperature for both sides to determine the properties. Later, the calculated value for the heat exchanger effectiveness is compared to the initial or previous value for agreement within a specified tolerance. After determining the average temperatures, the fluid properties, such as, viscosity μ, thermal conductivity k, and specific heat at constant pressure c_p are ascertained which allows a value for Prandtl number to be calculated (i.e., $N_{PR} = c_p \mu/k$). Curve-fits for the viscosity and thermal conductivity of air or a mixture of air and fuel were generated from tabulated property data published in the open literature [3]. Similar curve-fits for the specific heat of air or a mixture of air and fuel already existed [4]. A value for molecular weight of air or mixture of air and fuel is required to calculate specific volume at the core entrance (i.e., $v_1 = R_u T/pM$). Effects of humidity were not included in the calculations of fluid properties. Specific volumes are calculated using ratios of inlet and outlet conditions, and then a mean specific volume is determined for both air and gas sides.

REYNOLDS NUMBER

The heat exchanger flow-stream mass velocity is given by,

$$G = \frac{w}{A_c} \ , \tag{12}$$

and expressing the Reynolds number in terms of G yields:

$$N_R = \frac{4 r_h\, G}{\mu} \ . \tag{13}$$

STANTON NUMBER, COLBURN FACTOR, AND FRICTION FACTOR

The friction factor f, and the Colburn factor j are determined from the tabulated data of reference 1, corresponding to the selected fin surfaces and the calculated Reynolds number. For low Reynolds numbers that are not tabulated in reference 1, the following equations are used for the f and j factors,

$$f = \frac{K_1}{N_R} \tag{14}$$

and,

$$j = \frac{K_2}{N_R^{\,0.7}} \; . \tag{15}$$

The value of K_1 and K_2 have been determined by extending the graphs found in reference 1. The Stanton number is extracted from the Colburn factor which is defined as,

$$j = N_{ST} \, N_{PR}^{\;2/3} \; . \tag{16}$$

HEAT TRANSFER COEFFICIENT

The heat transfer coefficient h is a complex function of fluid properties, flow characteristics, and surface geometries and is defined by,

$$h = N_{ST} \, G \, c_p \; . \tag{17}$$

FIN EFFECTIVENESS

The fin effectiveness is defined as,

$$\eta_f = \frac{\tanh m\ell}{m\ell} \tag{18}$$

where, m is a fin effectiveness parameter given by,

$$m = \left(\frac{2h}{k\delta}\right)^{1/2} \tag{19}$$

and ℓ is the fin length from root to center,

$$\ell = \frac{b}{2} . \tag{20}$$

SURFACE EFFECTIVENESS

The total surface effectiveness is defined as,

$$\eta_o = 1 - \frac{A_{fr}}{A}(1-\eta_f) . \tag{21}$$

OVERALL COEFFICIENT OF HEAT TRANSFER

Using the surface effectiveness, heat transfer coefficient, the total heat transfer area, and the thermal wall resistance; the overall coefficient of heat transfer is expressed by

$$\frac{1}{U_a} = \frac{1}{\eta_{oa} h_a} + \frac{1}{(A_g/A_a)\eta_{og} h_g} + \frac{1}{k/(a/12)} . \tag{22}$$

NTU AND EXCHANGER EFFECTIVENESS

The flow stream capacity rate mentioned earlier is defined as,

$$C = wc_p . \tag{23}$$

A capacity rate is determined for both sides of the heat exchanger, and a capacity rate ratio is calculated for use later in the effectiveness equation i.e., Equation (25),

$$C_r = \frac{C_{min}}{C_{max}} = \frac{C_a}{C_g} < 1 . \tag{24}$$

With the aid of Equation (2) the number of transfer units is calculated, which with the capacity rate from Equation (23) are used to calculate heat exchanger effectiveness. Recalling the counterflow effectiveness equation,

$$\varepsilon = \frac{1 - e^{-NTU(1-C_r)}}{1 - C_r e^{-NTU(1-C_r)}} \quad . \tag{25}$$

Based on the above calculated effectiveness and Equation (1a) and (1b), the air and gas outlet temperatures can be calculated.

PRESSURE DROP

The total pressure drop in a compact heat exchanger is due to three major effects: (1) air-side header pressure drop, (2) core pressure drop, and (3) bend pressure drop. Different flow arrangements can result in lower or higher pressure losses. The counter-flow configuration shown in Figure 2 can result in a uniform velocity across the entire heat exchanger core, [5]. To keep the air-side header pressure loss at a minimum and for uniform flow distribution, the dynamic velocity ratio must be kept a constant, [5],

$$\frac{q_o}{q_i} = \frac{4}{\pi^2} = 0.405 \tag{26}$$

where,

$$q_i = \frac{\rho_i}{2g_c} V_i^{\,2} \tag{27}$$

and,

$$q_o = \frac{\rho_o}{2g_c} V_o^{\,2} \quad . \tag{28}$$

For the counter-flow configuration, the total pressure drop due to the headers on the air-side is defined as

$$\frac{\Delta p_{t_a}}{q_i} = 1 - \frac{q_o}{q_i} = 0.595 \quad . \tag{29}$$

To be consistent with reference 1, the header pressure drop must be divided by the inlet pressure p_{1_a},

$$\frac{\Delta p_{t_a}}{p_{1_a}} = \frac{.595}{p_{1_a}} \frac{\rho V_i^2}{2g_c} \tag{30}$$

By substituting the values for q_i and q_o into equation (26) the air-side velocity relationship can be determined,

$$V_o = .636\ V_i \left(\frac{\rho_i}{\rho_o}\right)^{1/2}. \tag{31}$$

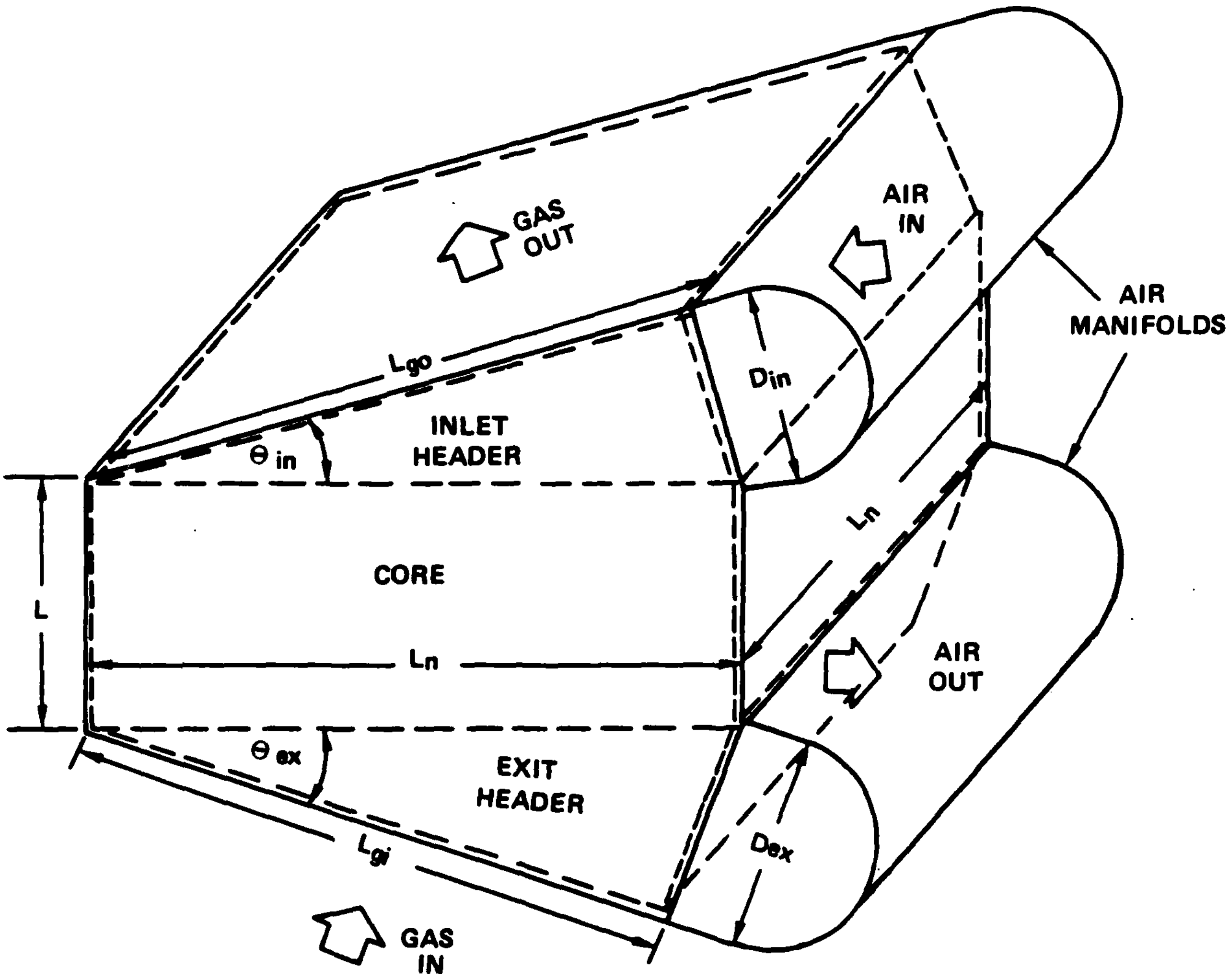

Figure 2 - Heat Exchanger Arrangement Used for Pressure Drop and Weight Estimations

The core pressure drop equation for a compact heat exchanger is complicated in that it consists of four components, [1]: (1) entrance effects, (2) flow acceleration, (3) core friction, and (4) exit effects. The flow-stream pressure drop relationship is defined as,

$$\frac{\Delta p_c}{p_1} = \frac{G^2 v_1}{2 g_c p_1} \left[\underbrace{(K_c + 1 - \sigma^2)}_{\text{entrance effect}} + \underbrace{2\left(\frac{v_2}{v_1} - 1\right)}_{\text{flow acceleration}} + \underbrace{f \frac{A}{A_c} \frac{v_m}{v_1}}_{\text{core friction}} - \underbrace{(1 - \sigma^2 - K_e) \frac{v_2}{v_1}}_{\text{exit effect}} \right] \tag{32}$$

and for the core friction parameter,

$$\frac{A}{A_c} = \frac{L}{r_h} . \tag{33}$$

Definition of the entrance and exit loss coefficient are from the literature [6]. The entrance loss coefficient, K_c is given by,

$$K_c = \frac{1 - 2C_c + C_c^2 (2K_d - 1)}{C_c^2} , \tag{34}$$

and the exit loss coefficient, K_e is defined as,

$$K_e = 1 - 2K_d \sigma + \sigma^2 . \tag{35}$$

Additional pressure loss must be considered since the headers have matrices. To account for the added matrix in each header, the core pressure drop has been increased by the percent of additional mean flow length in the headers. Therefore, equation (32) becomes; for the air-side,

$$\frac{\Delta p_a}{p_1} = \text{Eq (32)} \times \left(\frac{L_{g_i}}{2} + L + \frac{L_{g_o}}{2}\right)/L \tag{36}$$

and for the gas-side,

$$\frac{\Delta p_g}{p_1} = \text{Eq (32)} \times \left(1 + \frac{(D_i + D_o)}{2L}\right) . \qquad (37)$$

To estimate the bend pressure loss, it is assumed that a mitre elbow is similar to the configuration under consideration. The bend pressure loss is calculated for the air-side and gas-side inlet and exit conditions using the following expression,

$$\frac{\Delta p_b}{p_1} = \frac{K_b^*}{p_1} \frac{\bar{\rho} \bar{V}^2}{2g_c} . \qquad (38)$$

The bend loss coefficient, K_b^* is curve fitted for the mitre elbow [7]. Therefore, the total pressure drop of the heat exchanger for the air side is the summation of equations (30), (36), and (38) and for the gas-side is the summation of equations (37) and (38).

HEADER DIAMETER AND VELOCITY

Two important parameters which deserve attention during the design of heat exchangers are the diameters and velocities of the air-side inlet and outlet headers. From equation (31), the velocity relationship has already been determined. An inlet velocity must be assumed to calcuate an outlet velocity. By rearranging the equation of continuity, i.e.,

$$w = \rho A V \qquad (39)$$

the area of the header pipe or opening is determined,

$$A = \frac{w}{\rho V} . \qquad (40)$$

From Figure 2, it is assumed that the area through which the air enters or exits the manifolds is equal to the area of a circular pipe and is given by,

$$A = \frac{\pi D^2}{4} . \qquad (41)$$

Combining Equations (40) and (41) the diameter of the header is determined,

$$D = \left(\frac{4}{\pi}\frac{w}{\rho V}\right)^{1/2} . \tag{42}$$

The conditions at which density is defined depends on whether the inlet or outlet header is under consideration.

WEIGHT ESTIMATION

The heat exchanger weight estimation is comprised of five parts: (1) total weight of air-side fins, (2) total weight of gas-side fins, (3) sum of separating plates, (4) enclosure weight, and (5) header weights. The calculation of fin and plate weight is combined in a single equation, but done separately for the air-side and gas-side because these fin surfaces may vary within the regenerator. The basic equation for calculating fin and plate weight on either side is defined as,

$$\begin{matrix} W_a \\ \text{or} \\ W_g \end{matrix} = A\rho_m \left(A_{ft}\delta\psi_f + a(1 - A_{ft})\psi_p\right)/24 . \tag{43}$$

A plate factor ψ_p and a fin factor ψ_f in the above equation are determined from the physical dimensions of the air-side or gas-side fins. Basically, the plate factor ψ_p, relates the plate's non-flow length to the portion of non-flow length not accounted for by fin thickness. The fin factor, ψ_f, is calculated by dividing the total area by the extended fin area. Using the estimated fin and plate weights, W_a and W_g from above, and core volume, V, an average density for the core is determined,

$$\rho_c = \frac{W_a + W_g}{V} . \tag{44}$$

To help understand the estimated weight calculations of the headers and enclosure, figure 2 is used. Note that the headers are assumed to be triangular in shape. The total header volume which contributes weight to the heat exchanger is

determined based on the area of these triangle multiplied by the core's non-flow length (i.e., square root of frontal area). Assuming header density is equal to core density, header weight can then be expressed as,

$$W_{HD} = \rho_c \left(L_{g_i} D_o L_n + L_{g_o} D_i L_n\right)/2 \quad . \tag{45}$$

The enclosure weight is based on the following assumptions: (1) the average material density per unit surface area, $\overline{\rho_m}$, is approximately 15 lb/ft^2 and includes sheet metal, insulation, and supports, (2) the air manifolds have the same perimeter as would the circumferences of a circle with the diameter shown, (3) the enclosure is comprised of a four-sided box with no top and bottom and two air manifolds, and (4) the headers form a 90° triangle. From figure 2 and the preceding assumptions, the enclosure weight is defined as,

$$W_{ENCL} = 15 \times \left(4\, L_n\, L + \pi L_n\, (D_i + D_o) + L_{g_i} D_o + L_{g_o} D_i\right) . \tag{46}$$

Therefore, the total weight of the heat exchanger is the summation of the parts described above,

$$W_T = W_a + W_g + W_{HD} + W_{ENCL} \quad . \tag{47}$$

PROGRAM DESCRIPTION

The main program is called HTER and includes basic calculations, statements for input and output, and calls the subroutines: BENDLOS, STAT, SURF, and TRANSP. BENDLOS calculates the bend loss coefficient K_b^*, used in the pressure drop calculations, based on the angle at which the fluid turns through. STAT is a data bank for the friction factor and Colburn factor values from Kays and London [1], and calls a subroutine INT, which is an interpolation routine. SURF is the data bank for the plate fin characteristics, also from Kays and London [1], (Tables 9-3 a, b, c, and d). TRANSP returns fluid properties of air or combustion products, including viscosity, specific heat, and thermal conductivity. Input to the computer program is accomplished by reading a NAMELIST named "INDATA". The

NAMELIST INDATA identifies a succeeding list of input variables which can be input without specifing format. Included in the program is a BLOCK DATA DEFAULT for the NAMELIST INDATA, which defines a default value for each input variable. More about the NAMELIST statement and default values is given in the section titled INPUTS. The main program and subroutines are written in FORTRAN IV language for the CDC 6600 or 6700 computers.

The computer program has the following limitations and features, [2]:

1. The program assumes even distribution of flow across the flow cross section; i.e., the mass flow rate through any channel is simply the mass flow for sectional area of the channel. If this assumption is not true, effectiveness drops rapidly. Even flow distribution into the heat exchanger is not easy to achieve, especially in a short flow length, low pressure drop exchanger [8].

2. Effects of fouling and fin deformation are not included in the program.

3. An additional heat transfer (~2 to 5%) in a counterflow exchanger is obtained from the cross-counterflow in the headers. This was not considered in the program. In a pancake-shaped counterflow exchanger, the error in this assumption becomes appreciable.

4. All plate-fin surfaces given in Figures 9-3 to 9-7 of Kays and London [1] are included in the program except for 4.0 fins/in (plain).

The following sections describe the necessary input variables and resultant output variables of the computer program. Several sample cases of input data are given illustrating format, as well as, their corresponding output. Also described are error messages that may occur during the execution of the program. A complete listing of the computer program is included in the report as APPENDIX A, and the main program variables are defined in APPENDIX B.

INPUTS

Physical heat exchanger core parameters (i.e., lengths, fin types, frontal areas, etc.), air-side inlet header velocity, and heat exchanger flow conditions (i.e., pressure, temperatures, mass flows and fuel-air ratio), are provided to the program in the form of a NAMELIST called INDATA. The input conditions are required to be in U.S. units. A set of default values have been included in the program and include engine cycle data from figure 10 of reference 9. NAMELIST INDATA variables are as follows (with the default values shown to the right):

TYPA - air side fin type Default Value = 1
= 1 - plain fin
= 2 - louvered fin
= 3 - strip/offset fin
= 4 - wavy fin

NSA - air side surface number = 7
= 1 to 18 for plain fin
= 1 to 14 for louvered fin
= 1 to 12 for strip/offset fin
= 1 to 3 for wavy fin

TYPG - gas side fin type = 1
= 1 - plain fin
= 2 - louvered fin
= 3 - strip/offset fin
= 4 - wavy fin

NSG - gas side surface number = 7
= 1 to 18 for plain fin
= 1 to 14 for louvered fin
= 1 to 12 for strip/offset fin
= 1 to 3 for wavy fin

RLENI - initial flow length, ft = 3.0

RLI	- incremental flow length, ft	=	1.0
NL	- number of length iterations	=	5
IAFRA	- initial frontal area, ft^2	=	25.0
AFRAI	- value of frontal area increase per iteration, ft^2	=	25.0
NA	- number of frontal area iterations	=	4
WA	- air side mass flow rate, lb_m/sec	=	90.0
PINA	- air side inlet pressure, lb_f/in^2	=	116.4
TINA	- air side inlet temperature, °R	=	1040.5
PEXG	- gas side outlet pressure, lb_f/in^2	=	14.9
WG	- gas side mass flow rate, lb_m/sec	=	101.45
TING	- gas side inlet temperature, °R	=	1646.4
FAR	- fuel-to-air ratio	=	0.0145
VINPUT*	- header velocity, ft/sec	=	90.0

SAMPLE CASES

Included in this manual are eight (8) sample cases to illustrate using NAMELIST INDATA to define sets of input data. The data cards for these sample cases are shown in Figure 3. INDATA variable sets must begin with a $INDATA

* The user is advised to keep inlet air velocity below 100 ft/sec to ensure a design with good flow distribution and low losses

(where the $ is located in the second column) and each set ends with a $. The first data card has the $INDATA $, therefore, the default values are used to calculate the results shown as TABLE C-1 in APPENDIX C. A set of data items may consist of any subset of the variables names in NAMELIST INDATA. The value of variables not included in the subset on a following card remains unchanged.

```
$INDATA  TYPA=3,NSA=10,TYPG=3,NSG=1,RLENI=1.0  $
$INDATA  NSA=5,NSG=2,RLENI=14.0,NL=8,NA=3  $
$INDATA  TYPA=1,NSA=11,NSG=7,RLENI=2.0  $
$INDATA  NSG=5,RLENI=4.0  $
$INDATA  TYPA=2  $
$INDATA  PINA=223.6,TINA=878.9,WG=101.75,TING=1426.8,FAR=0.0175 $
$INDATA  PINA=111.9,TINA=790.5,WG=101.49,TING=1641.3,FAR=0.0149 $
$INDATA $
```

Figure 3 - Sample Cases For Namelist INDATA

The output consists of title headings, input variables, and computed results. APPENDIX C contains the corresponding output for the sample cases shown in Figure 3. Each data card produced a page of output. The first line of the output is a title heading: "CORE HEAT TRANSFER SURFACES". The next six lines of output give the heat transfer surface characteristics (i.e., hydraulic radius, compactness, plate spacing, etc.). "HEAT EXCHANGER CONDITIONS" is the next title heading and given on the following four lines are the mass flows, pressures, temperatures, and fuel-air ratio for the air and gas streams. These values are the INDATA variables. The next title heading is "HEADER DESIGN DETAILS," and given on the next four lines are the air-side inlet diameter and velocity. The computed values for the remaining output variables at various combinations of core

counterflow lengths and frontal areas comprise the rest of the output. With each new frontal area iteration, new column descriptors are printed. Contained in the tabulated values are as follows: counterflow length; heat exchanger core volume; frontal area; air side outlet pressure; gas side inlet pressure; air, gas, and total pressure drops in percent; air and gas side outlet temperatures; overall enclosure height; number of transfer units; heat exchanger effectiveness in percent; estimated weight; air-side exit header diameter and exit header velocity.

The results shown in Table C-1 (see APPENDIX C) were generated assuming plain fins, 11 fins per inch, and 0.25 inch plate spacing on both the air and gas sides. Counter-flow lengths are varied from 3 to 7 feet on 1 foot increments and total frontal flow area is varied from 25 to 100 ft^2 in 25 ft^2 increments. Air and gas inlet conditions are based on the gas turbine cycle data shown in Figure 10 in reference 9. An air-side inlet header velocity of 90 ft/sec is assumed in all sample cases. Although the physical characterisitics of the heat exchangers remain the same, air and gas side inlet conditions were changed in Tables C-2 and C-3 to reflect gas turbine cycle conditions shown as Figures 11 and 12, respectively, in reference 9. Air and gas side inlet conditions remain the same for Tables C-3 through C-8 while physical characterisitics of the heat exchangers are varied. Table C-4 shows the effect of changing the air-side fin type, from plain to louvered, but same fins/in, has on the performance of the heat exchanger. Table C-5 varies the gas-side fins/in from 11.1 to 6.2 and changes the initial flow length from 3 feet to 4 feet. In Table C-6 variations include the following: (1) air-side fin type from louvered to plain, (2) air-side and gas-side fins/in from 11.1 to 19.86 and 6.2 to 11.1, respectively, and (3) redefines the initial flow length from 4 feet to 2 feet. Table C-7 varies the air-side and gas-side fins/in from 19.86 to 6.2 and 11.1 to 3.01, respectively, and varies the initial flow length from 2 feet to 14 feet. Also, varied in Table C-7 are the number of length iterations and frontal area iterations from 5 to 8 and 4 to 3, respectively. Table C-8 varies the following assumptions: (1) fin types for both sides (air and gas) from plain to strip/offset, (2) the initial flow length from 14 feet to 1 foot, and (3) fins/in on the air-side and gas-side from 6.2 to 19.82 and 3.01 to 11.1, respectively.

ERROR MESSAGES

There are two basic error messages that may occur in the execution of the program. These messages are presented in this section along with reasons for their occurance.

(1) REYNOLDS NUMBER OUT OF RANGE OF PROGRAMMED TABLES - The Reynolds number on the air or gas side being too large causes this error message to occur. The reason why it occurs is that only the values from reference 1 were tabulated in the computer program and have an upper limit. The lower limit has been already discussed in the Method of Analysis.

(2) TRANSP INPUT OUT OF RANGE - The reason for this error message is that the entering fuel-air ratio to the subroutine TRANSP is too large or too small. A maximum value of 0.034826, and a minimum value of less than 0.0 are associated with the curve-fits for certain thermodynamic properties. Also, if the temperature is less than 500 °R or greater than 2000 °R the error message will occur. Results obtained within these ranges agree with the data from reference 3 within ± 1%.

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APPENDIX A

FORTRAN LISTING OF COMPUTER PROGRAM

```
*DECK HTER
      PROGRAM HTER(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C**********************************************************************
C
C     HEAT EXCHANGER TYPE TO BE SPECIFIED AS FOLLOWS-
C     WHERE TYPE:
C     TYPE 1 - PLAIN FIN              SURFACE NUMBER = 1 TO 18
C     TYPE 2 - LOUVERED FIN           SURFACE NUMBER = 1 TO 14
C     TYPE 3 - STRIP/OFFSET FIN       SURFACE NUMBER = 1 TO 12
C     TYPE 4 - WAVY FIN               SURFACE NUMBER = 1 TO  3
C
C**********************************************************************
C
      INTEGER TYPA, TYPG
C
      REAL ILA, ILG, K, KA, KBINA, KBEXA, KBING, KBEXG, KG, KCA, KCG,
     1     KDA, KDG, KEA, KEG, LA, LG, LHGING, LHGEXG, MA, MG, MAL, MGL,
     2     MUA, MUG, NARA, NARG, NE, NPRA, NPRG, NRA, NRG, NSTA, NSTG,
     3     NTU, IAFRA
C
      COMMON/INPUT/TYPA,NSA,TYPG,NSG,RLENI,RLI,NL,IAFRA,AFRAI,NA,WA,PINA
     2              ,TINA,PEXG,WG,TING,FAR,VINPUT
C
      NAMELIST/INDATA/TYPA,NSA,TYPG,NSG,RLENI,RLI,NL,IAFRA,AFRAI,NA,WA,
     2                 PINA,TINA,PEXG,WG,TING,FAR,VINPUT
C
      DATA RHO, PI, RU/ 485., 3.1416, 640.1 /
      DATA A,K,GC,ERROR/.01,12.,32.2,.001/
      DATA E,DELPA,DELPG /.5, 0.01, 0.03/
C
   35 READ(5,INDATA)
      IF(EOF(5)) 999,65
C
C*************** HEAT EXCHANGER CORE DIMENSIONS ********************
C
   65 CALL SURF(TYPA,NSA,AXA,BXA,SFA,BA,RHA,DELA,BETA,FRA,WFA,WPA)
      CALL SURF(TYPG,NSG,AXG,BXG,SFG,BG,RHG,DELG,BETG,FRG,WFG,WPG)
C
      VINA=VINPUT
      RHOINA=PINA/TINA/RU*1728.
      DINA=SQRT(4.*WA/RHOINA/VINA/PI)
      WRITE(6,110) TYPA,AXA,NXA,SFA,TYPG,AXG,NXG,SFG,BA,BG,RHA,RHG,
     2             DELA,DELG,BETA,BETG,FRA,FRG,WA,WG,PINA,PEXG,TINA,TING
     3             ,FAR,FAR
  110 FORMAT (1H1," CORE HEAT TRANSFER SURFACE",18X,"AIR-SIDE",29X,
     2        "GAS-SIDE" // 20X, "TYPE AND FIN DETAIL", 3X,I1,
     3        "-", F6.4, "-", I1, "-", F5.2,20X, I1, "-", F6.4, "-", I1,
     4        "-", F5.2 / 20X, "PLATE SPACING", 12X, F6.4, 2X, "IN",26X,
     5        F6.4, 2X, "IN" /20X, "HYDRAULIC RADIUS", 8X, F7.5, "  FT",
     6        25X,F7.5, "  FT" /20X, "FIN THICKNESS", 12X, F6.4, 2X,
     7        "IN",26X, F6.4, 2X, "IN" /20X, "COMPACTNESS", 13X, F7.1,
     8    2X,"SQFT/CUFT",15X,F10.1, 2X, "SQFT/CUFT" / 20X, "FIN/TOTAL",
     9        " AREA", 11X, F6.4, 2X, "FT/FT",23X, F6.4, 2X, "FT/FT"//
     *        "  HEAT EXCHANGER CONDITIONS",18X,"AIR-SIDE INLET",24X,
     1        "GAS-SIDE INLET",10X,"GAS-SIDE EXIT"//20X,"MASSFLOW",16X,
     2        F6.2,"  LB/SEC",23X,F6.2,"  LB/SEC",17X,"-"/20X,"PRESSURE"
     3   ,16X,F6.2,"  PSIA",32X,"-",18X,F6.2,"  PSIA"/20X,"TEMPERATURE",
     4        12X,F7.2,"  DEG R",23X,F7.2,"  DEG R",18X,"-"/20X,"FUEL-"
     5"AIR RATIO",12X,"0.0",34X,F6.4,20X,F6.4//"  HEADER DESIGN DETAILS"
```

```
     6          /)
      WRITE(6,115) VINA,DINA
  115 FORMAT(20X,"INLET AIR HEADER DIAMETER SIZED FOR INLET",
     2          " AIR VELOCITY =",F8.2,"  FT/SEC"/20X,"OUTLET ",
     3          "AIR HEADER DIAMETER SIZED FOR UNIFORM FLOW DISTRIBUTION "
     4          "AND MINIMUM HEADER LOSS"/20X,"INLET DIAMETER =",
     5           F6.2,"  FT"/20X,"EXIT AIR DIAMETER AND VELOCITY GIVEN "
     6          "BELOW"/)
      DO 700 I=1,NA
      I1=I-1
      AFRA=IAFRA+I1*AFRAI
      WRITE(6,130)
  130 FORMAT(1H0," LENGTH    VOLUME    AREA    P-A-EX    P-G-IN    DPA    DPG
     1  DPT    T-A-EX    T-G-EX     HEIGHT    NTU    EFFECT    WEIGHT     HEADE
     2R   VELOCITY"/"      FT        CU FT      SQFT      PSIA       PSIA     PCT
     3PCT     PCT    DEG R     DEG R         FT    ",10X,"PCT        LBS      DIA
     4FT     FT/SEC"/)
      DO 600 L=1,NL
      L1=L-1
      RLEN=RLENI+RLI*L1
      VOL=AFRA*RLEN
      PEXA=PINA*(1-DELPA)
      PING=PEXG*(1+DELPG)
C
C*************** HEAT TRANSFER AND FREE FLOW AREAS *****************
C
      PAA=BA/(BA+BG+2.*A)
      PAG=BG/(BA+BG+2.*A)
      ALHA=BETA*PAA
      ALHG=BETG*PAG
      AFRG=AFRA
      AA=ALHA*VOL
      AG=ALHG*VOL
      SIGA=ALHA*RHA
      SIGG=ALHG*RHG
      ACA=SIGA*AFRA
      ACG=SIGG*AFRG
      FLA=VOL/AFRA
      XNCFL=SQRT(AFRA)
      NXA=BXA
      NXG=BXG
      CMIN=1.
      CA=1.
      CG=1.
C
C*************** AVERAGE CORE FLUID PROPERTIES *************************
C
  150 TEXA= E*(TING-TINA)*CMIN/CA+TINA
      TAVA=(TEXA+TINA)*.5
      CALL TRANSP (TAVA, 0., CPA, KA, MUA, MA)
      TEXG= E*(TINA-TING)*CMIN/CG+TING
      TAVG=(TEXG+TING)*.5
      CALL TRANSP (TAVG, FAR, CPG, KG, MUG, MG)
C
C*************** AVERAGE CORE REYNOLDS NUMBERS *************************
C
      GA=WA/ACA
      NRA=4.*RHA*GA/MUA
      GG=WG/ACG
      NRG=4.*RHG*GG/MUG
```

```
C
C*************** STANTON NUMBER,COLBURN FACTOR,AND FRICTION FACTOR ****
C
      CALL STAT (TYPA, NSA, NRA, COLBFA,FA)
      IF(FA.EQ.Ø.)GO TO 7ØØ
      NPRA=CPA*MUA/KA
      NSTA=COLBFA/NPRA**.666
      HA=NSTA*GA*CPA*36ØØ.
      CALL STAT (TYPG, NSG, NRG, COLBFG, FG)
      IF(FG.EQ.Ø.) GO TO 7ØØ
      NPRG=CPG*MUG/KG
      NSTG=COLBFG/NPRG**.666
      HG=NSTG*GG*CPG*36ØØ.
C
C*************** FIN EFFECTIVENESS ******************************
C
      MAL=SQRT((2.*HA)/(K*DELA/12.))
      MGL=SQRT((2.*HG)/(K*DELG/12.))
      LA=(BA/12.)/2.
      LG=(BG/12.)/2.
      MAL=MAL*LA
      MGL=MGL*LG
      ETAFA=TANH(MAL)/MAL
      ETAFG=TANH(MGL)/MGL
C
C*************** SURFACE EFFECTIVENESS **********************
C
      ETAOA=1.-FRA*(1.-ETAFA)
      ETAOG=1.-FRG*(1.-ETAFG)
C
C*************** OVERALL COEFFICIENT OF HEAT TRANSFER *************
C
      RA=1./(ETAOA*HA)+1./((AG/AA)*ETAOG*HG)+1./(K/(A/12.))
      UA=1./RA
C
C*************** INLET AND EXIT LOSS COEFFICIENTS *******************
C
      CCA=.61ØØØØØØØ1-.14442945Ø71*SIGA+1.ØØ8Ø347435*SIGA**2
      CCA=CCA-1.731756ØØ83*SIGA**3+1.15594Ø7939*SIGA**4
      CCG=.61ØØØØØØØ1-.14442945Ø71*SIGG+1.ØØ8Ø347435*SIGG**2
      CCG=CCG-1.731756ØØ83*SIGG**3+1.15594Ø7939*SIGG**4
      NARA=NRA*1.E-4
      NARG=NRG*1.E-4
      KDA=1.1Ø6396Ø1Ø4-.13322445533*NARA+.11885428625*NARA**2
      KDA=KDA-.Ø3317Ø53Ø592*NARA**3
      KDG=1.1Ø6396Ø1Ø4-.13322445533*NARG+.11885428625*NARG**2
      KDG=KDG-.Ø3317Ø53Ø592*NARG**3
      KCA=(1.-2.*CCA+CCA**2*(2.*KDA-1.))/CCA**2
      KCG=(1.-2.*CCG+CCG**2*(2.*KDG-1.))/CCG**2
      KEA= 1.-2.*KDA*SIGA+SIGA**2
      KEG= 1.-2.*KDG*SIGG+SIGG**2
C
C*************** PRESSURE DROPS ******************************
C
      RHOEXA=PEXA/TEXA/RU*1728.
      RHOING=PING/TING/RU*1728.
      RHOEXG=PEXG/TEXG/RU*1728.
      VEXA=.636*VINA*SQRT(RHOINA/RHOEXA)
      DEXA=SQRT(4.*WA/RHOEXA/VEXA/PI)
      HINA=RHOINA/2./GC*VINA**2
```

```
      DELPAH=.595*HINA/PINA/144.
      ILA=1.-SIGA**2+KCA
      ILG=1.-SIGG**2+KCG
      SPVA=PINA/PEXA*TEXA/TINA
      SPVG=PING/PEXG*TEXG/TING
      ELA=(1.-SIGA**2-KEA)*SPVA
      ELG=(1.-SIGG**2-KEG)*SPVG
      SPVAM=2.*PINA/(PINA+PEXA)*TAVA/TINA
      SPVGM=2.*PING/(PING+PEXG)*TAVG/TING
      CFA=FA*AA/ACA*SPVAM
      CFG=FG*AG/ACG*SPVGM
      FAA=2.*(SPVA-1.)
      FAG=2.*(SPVG-1.)
      TLA=ILA+FAA+CFA-ELA
      TLG=ILG+FAG+CFG-ELG
      LHGING=SQRT(XNCFL**2-DEXA**2)
      LHGEXG=SQRT(XNCFL**2-DINA**2)
      ANGEXG=ATAN(DINA/LHGEXG)
      ANGING=ATAN(DEXA/LHGING)
      ANGINA=PI/2.-ANGEXG
      ANGEXA=PI/2.-ANGING
      HFXG=1.+((DINA+DEXA)/2./FLA)
      HFXA=(LHGING/2.+FLA+LHGEXG/2.)/FLA
      DELPAC=(GA/144./PINA)**2/2./GC*1545./MA*TINA*TLA*HFXA
      DELPGC=(GG/144./PING)**2/2./GC*1545./MG*TING*TLG*HFXG
      AHCMINA=SIGA*DINA*XNCFL
      AHCMING=SIGG*XNCFL*LHGING
      VINAH1=WA/RHOINA/AHCMINA
      VINGH1=WG/RHOING/AHCMING
      VINAC1=VINAH1*COS(ANGINA)
      VINGC1=VINGH1*COS(ANGING)
      CALL BENDLOS (ANGINA,KBINA)
      CALL BENDLOS (ANGING,KBING)
      VINAM=SQRT((VINAH1**2+VINAC1**2)/2.)
      VINGM=SQRT((VINGH1**2+VINGC1**2)/2.)
      DELPAB1=RHOINA*KBINA/2./GC*VINAM**2
      DELPGB1=RHOING*KBING/2./GC*VINGM**2
      AHCMEXA=SIGA*DEXA*XNCFL
      AHCMEXG=SIGG*LHGEXG*XNCFL
      VEXAH2=WA/RHOEXA/AHCMEXA
      VEXGH2=WG/RHOEXG/AHCMEXG
      VEXAC2=VEXAH2*COS(ANGEXA)
      VEXGC2=VEXGH2*COS(ANGEXG)
      CALL BENDLOS (ANGEXA,KBEXA)
      CALL BENDLOS (ANGEXG,KBEXG)
      VEXAM=SQRT((VEXAH2**2+VEXAC2**2)/2.)
      VEXGM=SQRT((VEXGH2**2+VEXGC2**2)/2.)
      DELPAB2=RHOEXA*KBEXA/2./GC*VEXAM**2
      DELPGB2=RHOEXG*KBEXG/2./GC*VEXGM**2
      DELPAB=(DELPAB1+DELPAB2)/PINA/144.
      DELPGB=(DELPGB1+DELPGB2)/PING/144.
      DELPA=DELPAC+DELPAH+DELPAB
      DELPG=DELPGC+DELPGB
      PEXA=PINA*(1.-DELPA)
      PING=PEXG*(1.+DELPG)
      PCDELPA=100.*DELPA
      PCDELPG=100.*DELPG
C
C*************** NTU AND HEAT EXCHANGER EFFECTIVENESS ****************
C
```

```
      CA=WA*CPA*3600.
      CG=WG*CPG*3600.
      CMIN=AMIN1(CA,CG)
      CR=AMIN1(CMIN/CA, CMIN/CG)
      NTU=AA*UA/CMIN
C  COUNTER-FLOW EFFECTIVENESS-NTU RELATIONSHIP
      X=EXP(-NTU*(1.-CR))
      NE=(1.-X)/(1.-CR*X)
      IF (ABS (NE/E-1.) .LT. ERROR) GO TO 300
      E=NE
      GO TO 150
  300 TEXA=NE*(TING-TINA)*CMIN/CA+TINA
      TEXG=NE*(TINA-TING)*CMIN/CG+TING
      DELPT=DELPA+DELPG
      PCDELPT=100.*DELPT
      PCNE=100.*NE
C
C*************** WEIGHT CALCULATIONS OF THE HEAT EXCHANGER ***********
C
      WTA=AA*RHO*(FRA*DELA*WFA + A*(1.-FRA)*WPA)/24.
      WTG=AG*RHO*(FRG*DELG*WFG + A*(1.-FRG)*WPG)/24.
      WPLA=15.*(4.*XNCFL*FLA+PI*XNCFL*(DINA+DEXA)+LHGING*DEXA
     2  +LHGEXG*DINA)
      WIE=(WTA+WTG)/VOL*(LHGING*DEXA*XNCFL+LHGEXG*DINA*XNCFL)/2.
      WHXT=WTA+WTG+WPLA+WIE
      OVALHT=DINA+DEXA+FLA
      WRITE(6,500)RLEN,VOL,AFRA,PEXA,PING,PCDELPA,PCDELPG,PCDELPT,TEXA,
     2              TEXG,OVALHT,NTU,PCNE,WHXT,DEXA,VEXA
  500 FORMAT(F7.1,F9.1,F8.1,2F9.2,3F6.2,2F9.1,F9.2,F8.2,F8.2,F9.1,F9.2
     2      ,F11.2)
      VINA=VINPUT
  600 CONTINUE
  700 CONTINUE
      GO TO 35
  999 STOP
      END
*DECK STATIS
      SUBROUTINE STAT (TYPE, NN, RE, NST, F)
C     ****************************************************************
C     SUBROUTINE STAT RETURNS STANTON NUMBERS AND FRICTION FLOW DATA
C     FOR THE TYPE HEAT EXCHANGER SPECIFIED
C     ****************************************************************
      INTEGER TYPE
      REAL NR,NST,IR,JR,KR,LR,IS,JS,KS,LS,MS,NS,MR
      DIMENSION AR(4,18),BR(4,18),CR(4,18),DR(4,18),ER(4,18),FR(4,18),
     *IR(4,18),JR(4,18),KR(4,18),LR(4,18),MR(4,18),NR(4,18),OR(4,18),
     *PR(4,18),QR(4,18),SR(4,18),TR(4,18),UR(4,18),VR(4,18),WR(4,18),
     *XR(4,18),YR(4,18),AS(4,18),BS(4,18),CS(4,18),DS(4,18),ES(4,18),
     *FS(4,18),GS(4,18),HS(4,18),IS(4,18),JS(4,18),KS(4,18),LS(4,18),
     *MS(4,18),NS(4,18),OS(4,18),PS(4,18),QS(4,18),RS(4,18),TS(4,18),
     *US(4,18),VS(4,18),WS(4,18),YS(4,18),XS(4,18),ZS(4,18)
     *,S(18),S1(18),S2(18),S3(18),C(14),D(14)
      DATA((S(I),I=1,18)=
     *2.0,3.01,3.97,5.3,6.2,9.03,11.1,11.11,14.77,15.08,19.86,10.27,
     *11.94,12.00,16.96,25.79,30.33,46.45)
      DATA(((AR(N,J),J=1,18),N=1,4)=
     *60000.,50[illegible]0.,40000.,30000.,25000.,20000.,15000.,12000.,10000.,800
     *0.,6000.,[illegible]00.,4000.,5*0.,.00228,.00237,.00248,.00264,.00274,.0028
     *8,.00305,.00320,.00333,.00347,.00363,.00373,.00379,5*0.,.00549,.00
     *562,.00579,.00601,.00616,.00638,.00672,.00703,.00734,.00778,.00847
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*,.00904,.01023,5*0.,0.8591,25.00,16*0.0)
 DATA(((BR(N,J),J=1,18),N=1,4)=
*45000.,40000.,30000.,25000.,20000.,15000.,12000.,10000.,8000.,6000
*.,5000.,4000.,3000.,5*0.,.00233,.00239,.00254,.00264,.00277,.00295
*,.00310,.00322,.00336,.00355,.00366,.00373,.00368,5*0.,.00602,.006
*08,.00630,.00645,.00667,.00700,.00732,.00762,.00808,.00886,.00950,
*.01045,.01190,5*0.,0.8591,25.00,16*0.0)
 DATA(((CR(N,J),J=1,18),N=1,4)=
*35000.,30000.,25000.,20000.,15000.,12000.,10000.,8000.,6000.,5000.
*,4000.,3000.,2500.,5*0.,.00246,.00254,.00263,.00276,.00291,.00302,
*.00316,.00330,.00348,.00357,.00367,.00367,.00357,5*0.,.00595,.0060
*5,.00620,.00638,.00667,.00695,.00720,.00761,.00826,.00880,.00963,
*.01110,.01230,5*0.,0.8591,25.00,16*0.0)
 DATA(((DR(N,J),J=1,18),N=1,4)=
*10000.,8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.
*,800.,600.,5*0.,.00373,.00397,.00427,.00448,.00477,.00515,.00535,.
*00554,.00571,.00606,.00654,.00728,.00851,5*0.,.00764,.00806,.00870
*,.00913,.00978,.0108,.0115,.0127,.0146,.0167,.0189,.0228,.0299,5*0
*.,0.7839,18.36,16*0.0)
 DATA(((ER(N,J),J=1,18),N=1,4)=
*12000.,10000.,8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200
*.,1000.,800.,5*0.,.00303,.00310,.00317,.00325,.00330,.00333,.00326
*,.00301,.00312,.00371,.00435,.00496,.00581,5*0.,.00708,.00735,.007
*68,.00807,.00838,.00875,.00923,.00958,.0103,.0127,.0152,.0176,.021
*1,5*0.,0.6251,17.24,16*0.0)
 DATA(((FR(N,J),J=1,18),N=1,4)=
*15000.,12000.,10000.,8000.,6000.,5000.,4000.,3000.,2500.,2000.,150
*0.,1200.,1000.,800.,4*0.,.00255,.00265,.00273,.00283,.00296,.00304
*,.00310,.00310,.00318,.00347,.00421,.00499,.00575,.00692,4*0.,.007
*08,.00740,.00763,.00799,.00842,.00870,.00903,.00980,.0106,.0122,
*.0152,.0182,.0214,.0262,4*0.,0.7233,21.40,16*0.0)
 DATA(((IR(N,J),J=1,18),N=1,4)=
*10000.,8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.
*,800.,600.,500.,4*0.,.00314,.00333,.00356,.00372,.00390,.00412,.00
*424,.00436,.00444,.00471,.00515,.00599,.00733,.00840,4*0.,.00878,.
*00923,.00971,.00991,.0103,.0112,.0119,.0139,.0149,.0169,.0190,.022
*8,.0294,.0350,4*0.,0.6471,17.80,16*0.0)
 DATA(((JR(N,J),J=1,18),N=1,4)=
*10000.,8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.
*,800.,600.,500.,4*0.,.00288,.00303,.00324,.00338,.00353,.00368,.00
*373,.00375,.00420,.00505,.00586,.00704,.00890,.0103,4*0.,.00768,.0
*0807,.00862,.00900,.00958,.0105,.0112,.0119,.0137,.0166,.0198,.024
*3,.0319,.0380,4*0.,0.7800,19.19,16*0.0)
 DATA(((KR(N,J),J=1,18),N=1,4)=
*10000.,8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.
*,800.,600.,500.,4*0.,.00310,.00326,.00352,.00367,.00389,.00417,.00
*435,.00456,.00495,.00538,.00585,.00663,.00791,.00898,4*0.,.00920,.
*00955,.0101,.0106,.0112,.0123,.0133,.0147,.0173,.0202,.0231,.0274,
*.0346,.0403,4*0.,0.7021,20.94,16*0.0)
 DATA(((LR(N,J),J=1,18),N=1,4)=
*6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.,800.,600.,
*500.,6*0.,.00308,.00310,.00309,.00309,.00322,.00352,.00420,.00491,
*.00562,.00662,.00815,.00930,6*0.,.00882,.00900,.00925,.00970,.0104
*0,.01205,.0151,.0182,.0215,.0264,.0343,.0405,6*0.,0.7273,20.65,16*
*0.0)
 DATA(((MR(N,J),J=1,18),N=1,4)=
*8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.,800.,
*600.,500.,400.,4*0.,.00320,.00337,.00348,.00363,.00382,.00395,.004
*10,.00443,.00497,.00567,.00672,.00834,.00960,.0113,4*0.,.00851,.00
*900,.00931,.00972,.0104,.0112,.0123,.0142,.0167,.0197,.0242,.0314,
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*.Ø372,.Ø457,4*Ø.,Ø.7378,18.57,16*Ø.Ø)
 DATA(((NR(N,J),J=1,18),N=1,4)=
*10000.,9000.,8000.,7000.,6000.,5000.,4000.,3000.,2000.,1500.,1200.
*,1000.,800.,600.,500.,400.,2*Ø.,.00295,.00299,.00303,.00310,.00318
*,.00328,.00341,.00372,.00445,.00523,.00608,.00682,.00797,.00869,
*.01101,.0129,2*Ø.,.00723,.00740,.00763,.00790,.00826,.00871,.00945
*,.01085,.01370,.01645,.0195,.0228,.0278,.0357,.0419,.0511,2*Ø.,Ø.8
*373,20.42,16*Ø.Ø)
 DATA(((OR(N,J),J=1,18),N=1,4)=
*10000.,9000.,8000.,7000.,6000.,5000.,4000.,3000.,2000.,1500.,1200.
*,1000.,800.,600.,500.,400.,300.,Ø.,.00294,.00302,.00309,.00317,.00
*322,.00323,.00330,.00317,.00329,.00379,.00437,.00498,.00589,.00729
*,.00833,.00980,.01215,Ø.,.00716,.00730,.00755,.00782,.00819,.00856
*,.00885,.00956,.01145,.01350,.0159,.0181,.0220,.0285,.0336,.0411,
*.0535,Ø.,Ø.6541,16.25,16*Ø.Ø)
 DATA(((PR(N,J),J=1,18),N=1,4)=
*8000.,7000.,6000.,5000.,4000.,3000.,2000.,1500.,1200.,1000.,800.,
*600.,500.,400.,300.,200.,2*Ø.,.00302,.00312,.00322,.00333,.00344,.
*00350,.00346,.00388,.00441,.00493,.00555,.00713,.00815,.00955,.011
*85,.01600,2*Ø.,.00851,.00881,.00928,.00980,.01045,.01128,.01285,.0
*1475,.0170,.0195,.0238,.0306,.0359,.0437,.0566,.0811,2*Ø.,Ø.6541,1
*6.25,16*Ø.Ø)
 DATA(((QR(N,J),J=1,18),N=1,4)=
*5000.,4000.,3000.,2000.,1500.,1200.,1000.,800.,600.,500.,400.,300.
*,6*Ø.,.00281,.00281,.00263,.00268,.00294,.00338,.00379,.00448,.005
*61,.00658,.00796,.01020,6*Ø.,.00809,.00835,.00875,.00962,.01088,.0
*125,.0144,.0178,.0232,.0275,.0339,.0442,6*Ø.,Ø.6213,13.27,16*Ø.Ø)
 DATA(((SR(N,J),J=1,18),N=1,4)=
*3000.,2000.,1500.,1200.,1000.,800.,600.,500.,400.,300.,8*Ø.,.00277
*,.00312,.00354,.00401,.00450,.00529,.00670,.00782,.00942,.01193,
*8*Ø.,.00831,.00981,.01165,.0134,.0153,.0185,.0240,.0286,.0351,.046
*Ø,8*Ø.,Ø.6555,13.80,16*Ø.Ø)
 DATA(((TR(N,J),J=1,18),N=1,4)=
*3000.,2000.,1500.,1200.,1000.,800.,600.,500.,400.,300.,8*Ø.,.00293
*,.00356,.00418,.00481,.00545,.00643,.00802,.00922,.0110,.0138,
*8*Ø.,.00981,.01185,.01395,.0162,.0189,.0230,.0302,.0361,.0448,.059
*5,8*Ø.,Ø.7352,17.85,16*Ø.Ø)
 DATA((C(I),I=1,14)=
*.375,.375,.500,.500,.375,.375,.1875,.250,.250,.375,.375,.500,.750,
*.750)
 DATA((D(I),I=1,14)=
*Ø.,1.,Ø.,1.,Ø.,1.,Ø.,Ø.,2.,Ø.,2.,Ø.,Ø.,2.)
 DATA((S1(I),I=1,14)=
*6.06,6.06,6.06,6.06,8.7,8.7,11.1,11.1,11.1,11.1,11.1,11.1,11.1,
*11.1)
 DATA(((VR(N,J),J=1,18),N=1,4)=
*10000.,8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.
*,800.,600.,500.,4*Ø.,.00551,.00593,.00651,.00690,.00738,.00805,.00
*849,.00900,.00970,.0104,.0112,.0124,.0144,.0160,4*Ø.,.0331,.0340,.
*0354,.0363,.0375,.0394,.0406,.0426,.0461,.0496,.0532,.0587,.0682,.
*0755,4*Ø.,1.2809,37.75,16*Ø.Ø)
 DATA(((WR(N,J),J=1,18),N=1,4)=
*10000.,8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.
*,800.,600.,5*Ø.,.00638,.00688,.00760,.00810,.00878,.00970,.0102,.0
*110,.0119,.0127,.0138,.0140,.0149,5*Ø.,.0494,.0510,.0531,.0547,.05
*68,.0596,.0620,.0646,.0696,.0745,.0795,.0860,.0962,5*Ø.,1.3119,57.
*72,16*Ø.Ø)
 DATA(((XR(N,J),J=1,18),N=1,4)=
*10000.,8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.
*,800.,600.,5*Ø.,.00568,.00605,.00655,.00690,.00734,.00791,.00829,.
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*00875,.00948,.0102,.0109,.0118,.0133,5*0.,.0300,.0310,.0322,.0332,
*.0347,.0366,.0381,.0402,.0438,.0474,.0512,.0571,.0667,5*0.,1.2700,
*40.02,16*0.0)
 DATA(((YR(N,J),J=1,18),N=1,4)=
*10000.,8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.
*,800.,600.,5*0.,.00598,.00645,.00714,.00760,.00809,.00895,.00941,.
*0100,.0108,.0113,.0118,.0122,.0128,5*0.,.0400,.0413,.0432,.0447,.0
*463,.0491,.0511,.0540,.0588,.0634,.0680,.0752,.0880,5*0.,1.1270.56
*.48,16*0.0)
 DATA(((AS(N,J),J=1,18),N=1,4)=
*10000.,8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.
*,800.,600.,500.,4*0.,.00542,.00583,.00640,.00678,.00737,.00794,.00
*835,.00885,.00951,.0103,.0112,.0126,.0149,.0169,4*0.,.0297,.0306,.
*0319,.0328,.0340,.0359,.0374,.0394,.0430,.0472,.0515,.0585,.0700,.
*0793,4*0.,1.3108,40.83,16*0.0)
 DATA(((BS(N,J),J=1,18),N=1,4)=
*8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.,800.,
*600.,500.,5*0.,.00630,.00690,.00730,.00790,.00870,.00950,.00980,.0
*106,.0113,.0121,.0131,.0145,.0154,5*0.,.0340,.0395,.0410,.0428,.04
*20,.0470,.0497,.0550,.0580,.0620,.0680,.0790,.0890,5*0.,1.2351,45.
*95,16*0.0)
 DATA(((CS(N,J),J=1,18),N=1,4)=
*6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.,800.,600.,
*500.,6*0.,.00690,.00740,.00802,.00899,.00960,.0103,.0113,.0122,.01
*30,.0142,.0161,.0177,6*0.,.0350,.0367,.0390,.0426,.0452,.0491,.055
*3,.0610,.0662,.0738,.0848,.0925,6*0.,1.1946,44.25,16*0.0)
 DATA(((DS(N,J),J=1,18),N=1,4)=
*8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.,800.,
*600.,500.,5*0.,.00666,.00728,.00771,.00825,.00901,.00954,.0102,.01
*12,.0119,.0125,.0137,.0155,.0168,5*0.,.0309,.0333,.0351,.0374,.040
*8,.0461,.0464,.0512,.0558,.0600,.0670,.0772,.0850,5*0.,1.3333,44.4
*1,16*0.0)
 DATA(((ES(N,J),J=1,18),N=1,4)=
*8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.,800.,
*600.,500.,5*0.,.00701,.00761,.00800,.00853,.00922,.00972,.0103,.01
*12,.0120,.0128,.0139,.0157,.0170,5*0.,.0349,.0364,.0375,.0390,.041
*2,.0430,.0456,.0502,.0550,.0595,.0662,.0780,.0870,5*0.,1.3332,44.3
*9,16*0.0)
 DATA(((FS(N,J),J=1,18),N=1,4)=
*10000.,8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.
*,800.,600.,500.,4*0.,.00548,.00588,.00645,.00684,.00793,.00811,.00
*861,.00930,.0102,.0111,.0121,.0135,.0156,.0170,4*0.,.0242,.0253,.0
*271,.0283,.0300,.0326,.0346,.0375,.0423,.0469,.0513,.0528,.0700,.0
*796,4*0.,1.3455,40.90,16*0.0)
 DATA(((GS(N,J),J=1,18),N=1,4)=
*8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.,800.,
*600.,500.,5*0.,.00590,.00650,.00694,.00752,.00835,.00889,.00960,.0
*105,.0112,.0119,.0130,.0148,.0161,5*0.,.0257,.0271,.0281,.0296,.03
*19,.0336,.0363,.0406,.0442,.0483,.0550,.0659,.0741,5*0.,1.2[illegible]4,38.
*30,16*0.0)
 DATA(((HS(N,J),J=1,18),N=1,4)=
*8000.,6000.,6000.,5000.,4000.,3000.,2500.,1500.,1200.,1000.,800.,
*600.,500.,5*0.,.00557,.00604,.00640,.00680,.00739,.00777,.00825,.0
*0888,.00950,.0104,.0117,.0137,.0150,5*0.,.0220,.0233,.0242,.0255,.
*0271,.0283,.0299,.0332,.0368,.0410,.0474,.0570,.0641,5*0.,1.1843,3
*3.125,16*0.0)
 DATA(((IS(N,J),J=1,18),N=1,4)=
*10000.,8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.
*,800.,600.,500.,4*0.,.00432,.00462,.00508,.00537,.00576,.00630,.00
*663,.00711,.00787,.00859,.00928,.0103,.0119,.0132,4*0.,.0151,.0158
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*,.0170,.0178,.0190,.0208,.0222,.0244,.0289,.0314,.0370,.0427,.0516
*,.0580,4*0.,1.0299,29.00,16*0.0)
 DATA(((JS(N,J),J=1,18),N=1,4)=
*10000.,8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.
*,800.,600.,500.,4*0.,.00440,.00469,.00510,.00537,.00572,.00621,.00
*655,.00699,.00762,.00831,.00894,.00981,.0112,.0122,4*0.,.0156,.016
*8,.0175,.0183,.0194,.0213,.0227,.0248,.0288,.0313,.0362,.0416,.050
*0,.0565,4*0.,0.9455,28.25,16*0.0)
 DATA((S2(I),I=1,12)=
*11.1,12.22,15.2,13.95,11.94,15.4,12.18,15.75,20.06,19.82,16.12,
*16.00)
 DATA(((KS(N,J),J=1,18),N=1,4)=
*8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.,800.,
*600.,500.,5*0.,.00525,.00580,.00620,.00669,.00740,.00789,.00850,.0
*0940,.0102,.0109,.0122,.0139,.0155,5*0.,.0197,.0209,.0218,.0231,.0
*253,.0272,.0298,.0348,.0394,.0438,.0500,.0595,.0665,5*0.,1.2012,33
*.25,16*0.0)
 DATA(((LS(N,J),J=1,18),N=1,4)=
*10000.,8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.
*,800.,600.,500.,4*0.,.00629,.00688,.00770,.00828,.00903,.0101,.010
*8,.0119,.0133,.0146,.0156,.0171,.0192,.0205,4*0.,.0394,.0413,.0440
*,.0458,.0487,.0530,.0560,.0607,.0680,.0752,.0826,.0942,.113,.130,
*4*0.,1.5887,65.00,16*0.0)
 DATA(((MS(N,J),J=1,18),N=1,4)=
*6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200,1000.,800.,600.,500
*.,400.,300.,4*0.,.00850,.00896,.00959,.01040,.01110,.01177,.01267,
*.01327,.01373,.01427,.01520,.01580,.01675,.01810,4*0.,.0487,.0498,
*.0516,.0540,.0558,.0584,.0628,.0676,.0726,.0800,.0913,.1010,.1145,
*.1390,4*0.,0.9810,41.70,16*0.0)
 DATA(((NS(N,J),J=1,18),N=1,4)=
*6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.,800.,600.,
*500.,400.,5*0.,.01110,.01170,.01250,.0137,.0144,.0155,.0168,.0181,
*.0192,.0204,.0223,.0233,.0247,5*0.,.0650,.0664,.0684,.0712,.0733,.
*0765,.0817,.0870,.0927,.1020,.1170,.131,.154,5*0.,1.6373,61.60,16*
*0.0)
 DATA(((OS(N,J),J=1,18),N=1,4)=
*7000.,6000.,5000.,4000.,3000.,2000.,1500.,1200.,1000.,800.,600.,
*500.,400.,300.,4*0.,.00452,.00471,.00492,.00522,.00575,.00682,.007
*44,.00830,.00911,.01045,.01255,.01415,.0166,.0205,4*0.,.0126,.0131
*,.0137,.0146,.0162,.0198,.0231,.0265,.0306,.0347,.0429,.0493,.0592
*,.0758,4*0.,1.1110,22.74,16*0.0)
 DATA(((PS(N,J),J=1,18),N=1,4)=
*6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.,800.,600.,
*500.,400.,300.,4*0.,.00510,.00537,.00570,.00617,.00650,.00692,.007
*56,.00809,.00864,.00952,.01107,.01227,.01407,.0169,4*0.,.0167,.017
*5,.0186,.0202,.0213,.0228,.0255,.0283,.0314,.0362,.0443,.0507,.060
*1,.0757,4*0.,0.9159,22.74,16*0.0)
 DATA(((QS(N,J),J=1,18),N=1,4)=
*9000.,8000.,7000.,6000.,5000.,4000.,3000.,2000.,1500.,1200.,1000.,
*800.,600.,500.,400.,300.,2*0.,.00512,.00530,.00557,.00591,.00635,.
*00692,.00782,.00933,.01065,.0119,.0129,.0141,.0169,.0191,.0023,.02
*78,2*0.,.0183,.0184,.0189,.0196,.0203,.0218,.0241,.0290,.0341,.038
*8,.0438,.0490,.0592,.0695,.0808,.1025,2*0.,1.5067,29.60,16*0.0)
 DATA(((RS(N,J),J=1,18),N=1,4)=
*6000.,5000.,4000.,3000.,2000.,1500.,1200.,1000.,800.,600.,500.,7*0
*.,.00619,.00649,.00713,.00813,.00992,.01125,.0124,.0136,.0154,.018
*5,.0209,7*0.,.0203,.0211,.0227,.0248,.0294,.0339,.0386,.0440,.0499
*,.0608,.0690,7*0.,1.6100,28.50,16*0.0)
 DATA(((TS(N,J),J=1,18),N=1,4)=
*3000.,2000.,1500.,1200.,1000.,800.,600.,500.,10*0.,.00855,.00995,.
```

```
     *01115,.0120,.0129,.0144,.0173,.0197,10*0.,.0309,.0349,.0387,.0422,
     *.0459,.0520,.0621,.0699,10*0.,1.5267,29.65,16*0.0)
      DATA(((US(N,J),J=1,18),N=1,4)=
     *3000.,2000.,1500.,1200.,1000.,800.,600.,500.,10*0.,.00880,.01015,.
     *01155,.0128,.0139,.0154,.0180,.0202,10*0.,.0420,.0450,.0492,.0535,
     *.0577,.0640,.0747,.0832,10*0.,1.5546,31.70,16*0.0)
      DATA(((VS(N,J),J=1,18),N=1,4)=
     *5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.,800.,600.,500.,
     *400.,300.,5*0.,.00721,.00764,.00822,.00859,.00908,.00987,.01060,.0
     *1123,.01205,.01352,.0150,.0176,.0266,5*0.,.0310,.0315,.0334,.0357,
     *.0379,.0400,.0429,.0464,.0517,.0607,.0679,.0781,.0937,5*0.,1.2249,
     *28.11,16*0.0)
      DATA(((WS(N,J),J=1,18),N=1,4)=
     *5000.,4000.,3000.,2000.,1500.,1200.,1000.,800.,600.,500.,8*0.,.007
     *78,.00838,.00925,.01085,.01205,.0132,.0142,.0159,.0188,.0209,8*0.,
     *.0295,.0307,.0328,.0373,.0418,.0460,.0502,.0568,.0675,.0765,8*0.,
     *1.6197,33.45,16*0.0)
      DATA((S3(I),I=1,3)=
     *11.44,11.5,17.8)
      DATA(((YS(N,J),J=1,18),N=1,4)=
     *8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.,800.,
     *600.,500.,5*0.,.00712,.00794,.00846,.00920,.01025,.0110,.0119,.013
     *2,.0144,.0153,.0165,.0175,.0179,5*0.,.0359,.0401,.0430,.0469,.0524
     *,.0563,.0615,.0691,.0758,.0819,.0888,.0984,.1045,5*0.,1.3812,49.80
     *,16*0.0)
      DATA(((XS(N,J),J=1,18),N=1,4)=
     *10000.,8000.,6000.,5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.
     *,800.,600.,500.,400.,3*0.,.00686,.00746,.00831,.00890,.00970,.0107
     *7,.01155,.0126,.0140,.0150,.0158,.0167,.0178,.0185,.0194,3*0.,.033
     *1,.0357,.0398,.0427,.0467,.0525,.0567,.0625,.0704,.0779,.0845,.092
     *6,.1035,.111,.118,3*0.,1.2860,47.20,16*0.0)
      DATA(((ZS(N,J),J=1,18),N=1,4)=
     *5000.,4000.,3000.,2500.,2000.,1500.,1200.,1000.,800.,600.,8*0.,.00
     *675,.00740,.00835,.00900,.00982,.0110,.0120,.0129,.0142,.0158,8*0.
     *,.0293,.0320,.0358,.0385,.0421,.0478,.0530,.0579,.0643,.0738,8*0.,
     *1.3911,44.28,16*0.0)
      DATA(((UR(N,J),J=1,18),N=1,4)=
     *2000.,1500.,1200.,1000.,800.,600.,500.,11*0.,.00294,.00349,.00418,
     *.00482,.00581,.00735,.00856,11*0.,.00118,.0135,.0157,.0183,.0228,.
     *0301,.0359,11*0.,0.6454,17.85,16*0.0)
      GO TO (100,1000,3000,5000),TYPE
  100 GO TO (110,120,130,140,150,200,210,220,230,240,250,260,270,280,290
     *,300,310,320),NN
  110 CALL INT(AR,RE,NST,F),RETURNS(6000)
  120 CALL INT(BR,RE,NST,F),RETURNS(6000)
  130 CALL INT(CR,RE,NST,F),RETURNS(6000)
  140 CALL INT(DR,RE,NST,F),RETURNS(6000)
  150 CALL INT(ER,RE,NST,F),RETURNS(6000)
  200 CALL INT(FR,RE,NST,F),RETURNS(6000)
  210 CALL INT(IR,RE,NST,F),RETURNS(6000)
  220 CALL INT(JR,RE,NST,F),RETURNS(6000)
  230 CALL INT(KR,RE,NST,F),RETURNS(6000)
  240 CALL INT(LR,RE,NST,F),RETURNS(6000)
  250 CALL INT(MR,RE,NST,F),RETURNS(6000)
  260 CALL INT(NR,RE,NST,F),RETURNS(6000)
  270 CALL INT(OR,RE,NST,F),RETURNS(6000)
  280 CALL INT(PR,RE,NST,F),RETURNS(6000)
  290 CALL INT(QR,RE,NST,F),RETURNS(6000)
  300 CALL INT(SR,RE,NST,F),RETURNS(6000)
  310 CALL INT(TR,RE,NST,F),RETURNS(6000)
```

```
 320 CALL  INT(UR,RE,NST,F),RETURNS(6000)
1000 GO TO (1100,1200,1300,1400,1500,1600,1700,1800,1900,2000,2100,
    *2200,2300,2400),NN
1100 CALL  INT(VR,RE,NST,F),RETURNS(6000)
1200 CALL  INT(WR,RE,NST,F),RETURNS(6000)
1300 CALL  INT(XR,RE,NST,F),RETURNS(6000)
1400 CALL  INT(YR,RE,NST,F),RETURNS(6000)
1500 CALL  INT(AS,RE,NST,F),RETURNS(6000)
1600 CALL  INT(BS,RE,NST,F),RETURNS(6000)
1700 CALL  INT(CS,RE,NST,F),RETURNS(6000)
1800 CALL  INT(DS,RE,NST,F),RETURNS(6000)
1900 CALL  INT(ES,RE,NST,F),RETURNS(6000)
2000 CALL  INT(FS,RE,NST,F),RETURNS(6000)
2100 CALL  INT(GS,RE,NST,F),RETURNS(6000)
2200 CALL  INT(HS,RE,NST,F),RETURNS(6000)
2300 CALL  INT(IS,RE,NST,F),RETURNS(6000)
2400 CALL  INT(JS,RE,NST,F),RETURNS(6000)
3000 GO TO (3100,3200,3300,3400,3500,3600,3700,3800,3900,4000,4100,4200
    *),NN
3100 CALL  INT(KS,RE,NST,F),RETURNS(6000)
3200 CALL  INT(LS,RE,NST,F),RETURNS(6000)
3300 CALL  INT(MS,RE,NST,F),RETURNS(6000)
3400 CALL  INT(NS,RE,NST,F),RETURNS(6000)
3500 CALL  INT(OS,RE,NST,F),RETURNS(6000)
3600 CALL  INT(PS,RE,NST,F),RETURNS(6000)
3700 CALL  INT(QS,RE,NST,F),RETURNS(6000)
3800 CALL  INT(RS,RE,NST,F),RETURNS(6000)
3900 CALL  INT(TS,RE,NST,F),RETURNS(6000)
4000 CALL  INT(US,RE,NST,F),RETURNS(6000)
4100 CALL  INT(VS,RE,NST,F),RETURNS(6000)
4200 CALL  INT(WS,RE,NST,F),RETURNS(6000)
5000 GO TO (5100,5200,5300,6000),NN
5100 CALL  INT(YS,RE,NST,F),RETURNS(6000)
5200 CALL  INT(XS,RE,NST,F),RETURNS(6000)
5300 CALL  INT(ZS,RE,NST,F),RETURNS(6000)
6000 RETURN
     END
*DECK SURF
     SUBROUTINE SURF (TYPE,NS,A1,B1,SF,PS,RH,DEL,BET,FR,WF,WP)
     INTEGER TYPE
     DIMENSION S(4,18,12)
     DATA(((S(1,I,N),N=1,12),I=1,18)=
    * 1.,.0000,0., 2.00,.750,.04740,.032,12.000,  76.1,.606,1.693,1.068
    *,2.,.0000,0., 3.01,.750,.03546,.032,12.000,  98.3,.706,1.460,1.107
    *,3.,.0000,0., 3.97,.750,.02820,.032,12.000, 119.4,.766,1.353,1.145
    *,4.,.0000,0., 5.30,.470,.02016,.006, 2.490, 188.0,.719,1.013,1.033
    *,5.,.0000,0., 6.20,.405,.01820,.010, 1.200, 204.0,.728,1.408,1.066
    *,6.,.0000,0., 9.03,.823,.01522,.008, 1.190, 244.0,.888,1.010,1.078
    *,7.,.0000,0.,11.10,.250,.01012,.006, 2.500, 367.0,.756,1.032,1.071
    *,8.,.0000,0.,11.11,.480,.01153,.008, 8.000, 312.0,.854,1.000,1.089
    *,9.,.0000,0.,14.77,.330,.00848,.006, 2.510, 420.0,.844,1.018,1.097
    1,0.,.0000,0.,15.08,.418,.00876,.006, 6.840, 414.0,.870,1.014,1.100
    1,1.,.0000,0.,19.86,.250,.00615,.006, 2.510, 561.0,.849,1.024,1.135
    1,2.,.0000,0.,10.27,.544,.01259,.010, 5.000, 289.9,.863,1.018,1.114
    1,3.,.0000,0.,11.94,.249,.00940,.006, 5.000, 393.0,.769,1.023,1.077
    1,4.,.0000,0.,12.00,.250,.00941,.006, 2.500, 392.7,.773,1.023,1.078
    1,5.,.0000,0.,16.96,.256,.00565,.006, 5.000, 607.8,.861,1.009,1.113
    1,6.,.0000,0.,25.79,.204,.00377,.006, 2.500, 855.6,.884,1.012,1.183
    1,7.,.0000,0.,30.33,.345,.00401,.006, 2.500, 812.5,.928,1.008,1.223
    1,8.,.0000,0.,46.45,.100,.00264,.002, 2.630,1332.5,.837,1.020,1.102
```

```
      * )
       DATA(((S(2,I,N),N=1,12),I=1,14)=
      * 1.,.3750,0., 6.06,.250,.01460,.006, 0.055, 256.0,.640,1.024,1.038
      *,2.,.3750,1., 6.06,.250,.01460,.006, 0.130, 256.0,.640,1.024,1.038
      *,3.,.5000,0., 6.06,.250,.01460,.006, 0.055, 256.0,.640,1.024,1.038
      *,4.,.5000,1., 6.06,.250,.01460,.006, 0.130, 256.0,.640,1.024,1.038
      *,5.,.3750,0., 8.70,.250,.01196,.006, 0.055, 307.0,.705,1.024,1.055
      *,6.,.3750,1., 8.70,.250,.01196,.006, 0.080, 307.0,.705,1.024,1.055
      *,7.,.1875,0.,11.10,.250,.01012,.006, 0.055, 367.0,.756,1.024,1.071
      *,8.,.2500,0.,11.10,.250,.01012,.006, 0.035, 367.0,.756,1.024,1.071
      *,9.,.2500,2.,11.10,.250,.01012,.006, 0.055, 367.0,.756,1.024,1.071
      1,0.,.3750,0.,11.10,.250,.01012,.006, 0.055, 367.0,.756,1.024,1.071
      1,1.,.3750,2.,11.10,.250,.01012,.006, 0.055, 367.0,.756,1.024,1.071
      1,2.,.5000,0.,11.10,.250,.01012,.006, 0.055, 367.0,.756,1.024,1.071
      1,3.,.7500,0.,11.10,.250,.01012,.006, 0.040, 367.0,.756,1.024,1.071
      1,4.,.7500,2.,11.10,.250,.01012,.006, 0.040, 367.0,.756,1.024,1.071
      * )
       DATA(((S(3,I,N),N=1,12),I=1,12)=
      * 1.,.2500,0.,11.10,.250,.01012,.006, 0.250, 367.0,.756,1.024,1.071
      *,2.,.0938,0.,12.22,.485,.01120,.004, 0.094, 340.0,.862,1.000,1.108
      *,3.,.1250,0.,15.20,.414,.00868,.006, 0.125, 417.0,.873,1.015,1.222
      *,4.,.1250,0.,13.95,.375,.00879,.010, 0.125, 381.0,.840,1.027,1.385
      *,5.,.5000,0.,11.94,.237,.00744,.006, 0.500, 461.0,.796,1.512,1.072
      *,6.,.2500,0.,15.40,.206,.00527,.006, 0.250, 642.0,.816,1.404,1.102
      *,7.,.1667,0.,12.18,.353,.00885,.004, 0.178, 422.0,.847,1.362,1.051
      *,8.,.1429,0.,15.75,.304,.00679,.004, 0.143, 526.0,.859,1.327,1.067
      *,9.,.1250,0.,20.06,.201,.00489,.004, 0.125, 698.0,.843,1.373,1.087
      1,0.,.1250,0.,19.82,.205,.00509,.004, 0.125, 680.0,.841,1.377,1.086
      1,1.,.1250,0.,16.12,.206,.00611,.006, 0.125, 660.0,.823,1.381,1.107
      1,2.,.1250,0.,16.00,.255,.00514,.006, 0.125, 550.0,.845,1.366,1.106
      * )
       DATA(((S(4,I,N),N=1,12),I=1, 3)=
      * 1.,.3750,0.,11.48,.413,.01060,.006, 0.078, 351.0,.847,1.015,1.074
      *,2.,.3750,0.,11.50,.375,.00993,.010, 0.078, 347.0,.822,1.027,1.130
      *,3.,.3750,0.,17.80,.413,.00696,.006, 0.078, 514.0,.892,1.015,1.120
      * )
       A1=S(TYPE,NS,2)
       B1=S(TYPE,NS,3)
       SF=S(TYPE,NS,4)
       PS=S(TYPE,NS,5)
       RH=S(TYPE,NS,6)/4.
       DEL=S(TYPE,NS,7)
       BET=S(TYPE,NS,9)
       FR=S(TYPE,NS,10)
       WF=S(TYPE,NS,11)
       WP=S(TYPE,NS,12)
       RETURN
       END
*DECK DEFAULT
       BLOCK DATA DEFAULT
C
C      DEFAULT VALUES FOR NAMELIST INDATA
C
       REAL IAFRA
       COMMON/INPUT/TYPA,NSA,TYPG,NSG,RLENI,RLI,NL,IAFRA,AFRAI,NA,WA,PINA
      2              ,TINA,PEXG,WG,TING,FAR,VINPUT
C
       DATA TYPA,NSA,TYPG,NSG /1, 7, 1, 7 /
       DATA RLENI,RLI,NL,IAFRA,AFRAI,NA /3.0, 1.0, 5, 25, 25.0, 4 /
       DATA WA,PINA,TINA /90.0, 116.4, 1040.5 /
       DATA WG,PEXG,TING /101.45, 14.90, 1646.4 /
```

```
      DATA FAR,VINPUT /Ø.Ø145, 9Ø.Ø /
C
      END
*DECK INTERP
      SUBROUTINE INT(NR,RE,NST,F),RETURNS(A)
      REAL NR,NST
      DIMENSION NR(4,18)
      N=Ø
      N=N+1
      J=Ø
    5 J=J+1
      IF(RE.LT.NR(N,J)) GO TO 5
      IF(J.EQ.1) GO TO 19
      IF(NR(1,J).EQ.Ø.) GO TO 1Ø
      X=NR(1,J-1)-NR(1,J)
      Y=NR(1,J-1)-RE
      Z=Y/X
      NST=Z*(NR(2,J)-NR(2,J-1))
      NST=NR(2,J-1)+NST
      F=Z*(NR(3,J)-NR(3,J-1))
      F=NR(3,J-1)+F
      GO TO 2Ø
   1Ø F=NR(4,2)/RE
      NST=NR(4,1)/RE**Ø.7
      GO TO 2Ø
   19 WRITE(6,15) RE
   15 FORMAT(1X,"REYNOLDS NUMBER OUT OF RANGE OF PROGRAMMED TABLES = ",
     1F1Ø.1)
      NST=Ø.
      F=Ø.
   2Ø RETURN A
      END
*DECK TRANSP
      SUBROUTINE TRANSP(T,FAR,CP,TK,MU,MW)
      REAL MU,MUA,MUF,MUG,MW
C
C***********************************************************************
C
      DATA A1,A2,A3,A4,A5,A6,A7,A8/1.Ø11554ØE-25,-1.452677ØE-21,
     A7.6215767E-18,-1.5128259E-14,-6.7178376E-12,6.5519486E-Ø8,
     B-5.1536879E-Ø5,2.5Ø2ØØ51E-Ø1/

      DATA B1,B2,B3,B4,B5,B6,B7,B8/7.267871ØE-25,-1.3335668E-2Ø,
     A1.Ø212913E-16,-4.2Ø511Ø4E-13,9.9686793E-1Ø,-1.37719Ø1E-Ø6,
     B1.225863ØE-Ø3,7.3816638E-Ø2/

      DATA C1,C2,C3,C4,C5,C6,C7/-6.21764Ø1E-22,7.1827364E-18,
     A-3.141Ø386E-14,6.721472ØE-11,-7.5336781E-8,6.1979Ø74E-5,
     B-4.81E-3/

      DATA D1,D2,D3,D4,D5,D6,D7/1.Ø4Ø4582E-19,-7.5213293E-16,
     A2.16376Ø7E-12,-3.1593Ø96E-9,2.4649233E-6,-9.Ø8ØØ2Ø4E-4,1.1Ø73E-1/

      DATA E1,E2,E3,E4,E5,E6,E7/2.4724974E-21,-1.6756272E-17,
     A4.15Ø5396E-14,-3.99Ø6519E-11,-9.1347177E-9,8.8743855E-5,
     B2.98E-3/

      DATA F1,F2,F3,F4,F5,F6,F7/-2.Ø255169E-19,1.4196996E-15,
     A-3.9713Ø25E-12,5.6582466E-9,-4.3414613E-6,1.8135ØØ9E-3,-3.3929E-1/
```

```
C
      IF(T .LT. 500. .OR. T .GT. 2000.) GO TO 100
      IF(FAR .LT. 0.0 .OR. FAR .GT. 0.034826) GO TO 100
      CPA=((((((A1*T+A2)*T+A3)*T+A4)*T+A5)*T+A6)*T+A7)*T+A8
      CP=CPA
      IF(FAR.EQ.0.) GO TO 30
      CPF=((((((B1*T+B2)*T+B3)*T+B4)*T+B5)*T+B6)*T+B7)*T+B8
      CPG=(CPA+FAR*CPF)/(1.+FAR)
      CP=CPG
   30 TKA=(((((C1*T+C2)*T+C3)*T+C4)*T+C5)*T+C6)*T+C7
      TK=TKA/3600.
      IF(FAR.EQ.0.) GO TO 40
      TKF=(((((D1*T+D2)*T+D3)*T+D4)*T+D5)*T+D6)*T+D7
      TKG=(TKA+FAR*TKF)/(1.+FAR)
      TK=TKG/3600.
   40 MUA=(((((E1*T+E2)*T+E3)*T+E4)*T+E5)*T+E6)*T+E7
      MU=MUA/3600.
      IF(FAR.EQ.0.0) GO TO 50
      MUF=(((((F1*T+F2)*T+F3)*T+F4)*T+F5)*T+F6)*T+F7
      MUG=(MUA+FAR*MUF)/(1.+FAR)
      MU=MUG/3600.
   50 MW=28.97-.946186*FAR
      RETURN
  100 WRITE (6, 101) T, FAR
  101 FORMAT(10X,25HTRANSP INPUT OUT OF RANGE,5X,7HTEMP = ,F8.2,5X,6HFAR
     * = ,F7.4)
      RETURN
      END
*DECK BENDLOS
      SUBROUTINE BENDLOS(X,Y)
C
      Z=X*57.29578
      Y=.2922713E-01-.2639695E-02*Z+.2272872E-03*Z**2-.1850293E-05*Z**3+
     2  .3655184E-07*Z**4-.449784E-09*Z**5+.2088911E-11*Z**6
C
      RETURN
      END
```

APPENDIX B

MAIN PROGRAM VARIABLES

A	plate thickness, in
AA/G	total heat transfer, ft^2
ACA/G	minimum free flow area, ft^2
AFRA/G	frontal area, ft^2
AFRAI	value of frontal area increase per iteration, ft^2
AHCMEXA/G	header core matrix exit area, ft^2
AHCMINA/G	header core matrix inlet area, ft^2
ALHA/G	ratio of total transfer on one side to total volume of exchanger
ANGEXA/G	header core exit angle, radians
ANGINA/G	header core inlet angle, radians
AXA/G	fins/in
BA/G	plate spacing, in
BETA/G	ratio of total heat transfer area to volume between plates, ft^2/ft^3
BXA/G	denotes different fins
CA/G	capacity rate, BTU/(hr °R)
CCA/G	jet contraction-area ratio
CFA/G	pressure effect core friction
CMIN	minimum flow-stream capacity rate, BTU/(hr °R)
COLBFA/G	Colburn factor
CPA/G	specific heat, BTU/(hr °R)
CR	minimum capacity rate ratio
DELA/G	fin thickness, in
DELPA/G	total pressure loss on one side
DELPAB/GB	bend pressure loss
DELPAB1/GB1	inlet bend pressure loss
DELPAB2/GB2	exit bend pressure loss
DELPAC/GC	core pressure loss
DELPAH	air-side header pressure loss
DELPT	total heat exchanger pressure loss
DEXA	air-side exit header diameter, ft
DINA	air-side inlet header diameter, ft

E	heat exchanger effectiveness
ELA/G	pressure loss exit effects
ERROR	heat exchanger effectiveness tolerance
ETAFA	fin effectiveness
ETAOA/G	surface effectiveness
FA/G	friction factor
FAA/G	pressure effect flow acceleration
FAR	fuel to air ratio
FLA	free stream counter-flow length, ft
FRA/G	fin area/total area
GA/G	flow stream mass velocity, $lb_m/(hr\ ft^2)$
GC	gravitational constant in Newton's second law, $lb_m ft/(lb_f\ sec^2)$
HA/G	unit film conductance, BTU/(hr ft^2 °R)
HFXA/G	ratio factor used in core pressure loss to account for matrix in headers
HINA	air-side dynamic velocity, lb_f/ft^2
I	counter
IAFRA	initial frontal area, ft^2
ILA/G	pressure loss entrance effects
I1	counter
K	unit thermal conductivity, BTU/(hr ft^2 °R/ft)
KA/G	fluid thermal conductivity, BTU/(hr ft °R)
KBEXA/G	exit bend loss coefficient
KBINA/G	inlet bend loss coefficient
KCA/G	contraction-loss coefficient
KDA/G	momentum velocity-distribution coefficient
KEA/G	expansion-loss coefficient
L	counter
LA/G	fin length from root to center, ft
LHGEXG	exit gas-side header length, ft
LHGING	inlet gas-side header length, ft
L1	counter
MA/G	molecular weight
MAL/GL	fin effectiveness parameter

MUA/G	viscosity coefficient, $lb_m/(hr\ ft)$
NA	number of frontal area interations
NARA/G	Reynolds number to the 10^{-4}
NE	heat exchanger effectinvess
NL	number of length interation
NPRA/G	Prandtl number
NRA/G	Reynolds number
NSA/G	surface number used as input parameter
NSTA/G	Staton number
NTU	number of heat transfer units
NXA/G	denotes different fins
OVALHT	overall length of heat exchanger enclosure, ft
PAA/G	percent area opening on one side to total area
PCDELPA/G	percent total pressure drop on one side, %
PCDELPT	percent total pressure drop of heat exchanger, %
PCNE	percent heat exchanger effectiveness, %
PEXA/G	outlet pressure on one side, lb_f/in^2
PI	π - constant = 3.1416
PINA/G	inlet pressure on one side, lb_f/in^2
RA	parameter used in overall coefficient of heat transfer, $hr\ ft^2\ °R/BTU$
RHA/G	hydraulic radius, ft
RHO	density of heat exchanger material, lb_m/ft^3
RHOEXA/G	exit density of fluid on one side of heat exchanger headers, lb_m/ft^3
RHOINA/G	inlet density of fluid on one side of heat exchanger headers, lb_m/ft^3
RLEN	flow length, ft
RLENI	initial flow length, ft
RLI	value of length increase per iteration, ft
RU	gas constant, $in\text{-}lb_f/(lb_m\ °R)$
SFA/G	fins/in
SIGA/G	ratio of free-flow area to frontal area
SPVA/G	specific volume, ft^3/lb_m
SPVAM/GM	mean conditions specific volume, ft^3/lb_m
TAVA/G	average temperature, °R

TEXA/G	outlet temperature, °R
TINA/G	inlet temperature, °R
TLA/G	sum of pressure loss effects
TYPA/G	fin type
UA	overall coefficient of heat transfer, BTU/(hr ft^2 °R)
VEXA	air-side exit header velocity, ft/sec
VEXAC2/GC2	core exit velocity, ft/sec
VEXAH2/GH2	header exit velocity, ft/sec
VEXAM/GM	mean exit velocity, ft/sec
VINA	air-side inlet header velocity, ft/sec
VINAC1/GC1	inlet core velocity, ft/sec
VINAH1/GH1	inlet header velocity, ft/sec
VINAM/GM	mean inlet velocity, ft/sec
VINPUT	input velocity, ft/sec
VOL	volume, ft^3
WA/G	mass flow rate, lb/sec
WFA/G	factor to account for non-extended fin suface weight
WHXT	heat exchanger weight, lb
WIE	estimated weight of header, lb
WPA/G	factor to account for plate in weight calculations
WPLA	total weight of enclosure, lb
WTA/G	total weight of fins and plate, lb
X	expontial variable used in effectiveness calculations
XNCFL	heat exchanger non-flow length, ft

NOTE:

A/G air or gas-side

APPENDIX C

OUTPUT FOR SAMPLE CASES

TABLE C-1

CORE HEAT TRANSFER SURFACE	AIR-SIDE	GAS-SIDE
TYPE AND FIN DETAIL	1-0.0000-0-11.10	1-0.0000-0-11.10
PLATE SPACING	.2500 IN	.2500 IN
HYDRAULIC RADIUS	.00253 FT	.00253 FT
FIN THICKNESS	.0060 IN	.0060 IN
COMPACTNESS	367.0 SQFT/CUFT	367.0 SQFT/CUFT
FIN/TOTAL AREA	.7560 FT/FT	.7560 FT/FT

HEAT EXCHANGER CONDITIONS	AIR-SIDE INLET	GAS-SIDE INLET	GAS-SIDE EXIT
MASSFLOW	90.00 LB/SEC	101.49 LB/SEC	-
PRESSURE	111.90 PSIA	-	14.90 PSIA
TEMPERATURE	790.50 DEG R	1641.30 DEG R	-
FUEL-AIR RATIO	0.0	.0149	.0149

HEADER DESIGN DETAILS

INLET AIR HEADER DIAMETER SIZED FOR INLET AIR VELOCITY = 90.00 FT/SEC
OUTLET AIR HEADER DIAMETER SIZED FOR UNIFORM FLOW DISTRIBUTION AND MINIMUM HEADER LOSS
INLET DIAMETER = 1.81 FT
EXIT AIR DIAMETER AND VELOCITY GIVEN BELOW

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
3.0	75.0	25.0	110.74	19.58	1.04	31.41	32.44	1424.8	1100.7	7.46	2.43	74.85	8788.9	2.65	77.74
4.0	100.0	25.0	110.62	19.99	1.15	34.18	35.33	1476.0	1054.3	8.49	3.23	80.80	10323.8	2.67	79.14
5.0	125.0	25.0	110.50	20.47	1.26	37.37	38.63	1510.4	1022.6	9.50	4.04	84.80	11934.2	2.69	80.13
6.0	150.0	25.0	110.37	20.92	1.36	40.40	41.77	1535.1	999.8	10.52	4.84	87.66	13541.6	2.70	80.83
7.0	175.0	25.0	110.25	21.35	1.47	43.30	44.77	1553.5	982.7	11.53	5.64	89.80	15147.3	2.71	81.36

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
3.0	150.0	50.0	111.27	16.75	.56	12.44	13.01	1461.5	1067.4	7.48	2.97	79.12	16504.4	2.66	78.55
4.0	200.0	50.0	111.23	17.03	.60	14.30	14.90	1507.4	1025.5	8.50	3.95	84.44	19558.8	2.68	79.77
5.0	250.0	50.0	111.19	17.27	.64	15.93	16.57	1537.6	997.5	9.51	4.93	87.95	22603.6	2.70	80.60
6.0	300.0	50.0	111.14	17.51	.68	17.54	18.22	1558.8	977.7	10.52	5.91	90.42	25642.2	2.71	81.17
7.0	350.0	50.0	111.10	17.75	.71	19.10	19.81	1574.4	963.1	11.53	6.89	92.23	28677.2	2.72	81.59

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
3.0	225.0	75.0	111.43	15.93	.42	6.90	7.32	1478.2	1052.2	7.48	3.28	81.05	24068.8	2.67	78.94
4.0	300.0	75.0	111.41	16.08	.44	7.92	8.36	1521.4	1012.5	8.50	4.36	86.07	28532.2	2.69	80.09
5.0	375.0	75.0	111.39	16.23	.46	8.92	9.38	1549.5	986.4	9.52	5.45	89.34	32980.3	2.70	80.84
6.0	450.0	75.0	111.37	16.37	.48	9.90	10.38	1569.1	968.1	10.53	6.53	91.62	37420.0	2.71	81.35
7.0	525.0	75.0	111.35	16.52	.50	10.86	11.36	1583.5	954.6	11.53	7.61	93.28	41854.6	2.72	81.73

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
3.0	300.0	100.0	111.50	15.61	.36	4.74	5.10	1501.4	1031.0	7.49	3.80	83.74	31534.6	2.68	79.53
4.0	400.0	100.0	111.48	15.71	.38	5.45	5.82	1540.6	994.7	8.51	5.06	88.31	37387.5	2.70	80.57
5.0	500.0	100.0	111.46	15.82	.39	6.15	6.54	1565.8	971.2	9.52	6.31	91.23	43221.4	2.71	81.23
6.0	600.0	100.0	111.45	15.92	.40	6.85	7.25	1583.0	955.1	10.53	7.57	93.23	49045.0	2.72	81.68
7.0	700.0	100.0	111.43	16.02	.42	7.54	7.96	1595.5	943.4	11.54	8.83	94.67	54862.5	2.72	82.01

TABLE C-2

CORE HEAT TRANSFER SURFACE	AIR-SIDE	GAS-SIDE
TYPE AND FIN DETAIL	1-0.0800-[illegible]-11.10	1-0.0800-[illegible]-11.10
PLATE SPACING	.2500 IN	.2500 IN
HYDRAULIC RADIUS	.00253 FT	.00253 FT
FIN THICKNESS	.0060 IN	.0060 IN
COMPACTNESS	367.0 SQFT/CUFT	367.0 SQFT/CUFT
FIN/TOTAL AREA	.7560 FT/FT	.7560 FT/FT

HEAT EXCHANGER CONDITIONS	AIR-SIDE INLET	GAS-SIDE INLET	GAS-SIDE EXIT
MASSFLOW	90.00 LB/SEC	101.45 LB/SEC	-
PRESSURE	116.40 PSIA	-	14.90 PSIA
TEMPERATURE	1040.50 DEG R	1646.40 DEG R	-
FUEL-AIR RATIO	0.0	.0145	.0145

HEADER DESIGN DETAILS

INLET AIR HEADER DIAMETER SIZED FOR INLET AIR VELOCITY = 90.00 FT/SEC
OUTLET AIR HEADER DIAMETER SIZED FOR UNIFORM FLOW DISTRIBUTION AND MINIMUM HEADER LOSS
INLET DIAMETER = 2.05 FT
EXIT AIR DIAMETER AND VELOCITY GIVEN BELOW

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
3.0	75.0	25.0	115.21	20.25	1.03	35.92	36.95	1493.3	1262.4	7.88	2.44	74.73	8999.1	2.83	68.93
4.0	100.0	25.0	115.08	20.46	1.14	37.34	38.47	1529.4	1230.0	8.90	3.25	80.69	10609.2	2.84	69.78
5.0	125.0	25.0	114.95	20.93	1.25	40.46	41.71	1553.7	1208.0	9.91	4.06	84.70	12216.1	2.85	70.37
6.0	150.0	25.0	114.82	21.46	1.36	44.05	45.41	1571.2	1192.2	10.92	4.87	87.58	13821.5	2.86	70.82
7.0	175.0	25.0	114.69	21.92	1.47	47.09	48.56	1584.2	1180.3	11.92	5.67	89.74	15427.6	2.87	71.15

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
3.0	150.0	50.0	115.78	16.95	.53	13.78	14.31	1518.4	1239.9	7.89	2.97	78.08	17110.9	2.83	69.33
4.0	200.0	50.0	115.74	17.25	.57	15.77	16.34	1550.9	1210.6	8.90	3.95	84.24	20164.9	2.85	70.08
5.0	250.0	50.0	115.69	17.52	.61	17.59	18.20	1572.3	1191.1	9.91	4.93	87.78	23203.7	2.86	70.57
6.0	300.0	50.0	115.65	17.78	.65	19.32	19.97	1587.4	1177.4	10.92	5.91	90.27	26238.9	2.87	70.93
7.0	350.0	50.0	115.61	18.03	.68	21.00	21.69	1598.6	1167.2	11.92	6.89	92.11	29271.3	2.87	71.19

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
3.0	225.0	75.0	115.95	16.06	.39	7.79	8.17	1531.8	1227.9	7.89	3.32	81.08	24989.4	2.84	69.58
4.0	300.0	75.0	115.93	16.23	.41	8.93	9.34	1562.3	1200.3	8.91	4.42	86.11	29440.2	2.85	70.27
5.0	375.0	75.0	115.90	16.39	.43	10.03	10.45	1582.1	1182.2	9.92	5.53	89.39	33881.2	2.86	70.73
6.0	450.0	75.0	115.88	16.56	.45	11.11	11.56	1595.9	1169.6	10.92	6.63	91.67	38315.7	2.87	71.05
7.0	525.0	75.0	115.86	16.71	.47	12.17	12.64	1606.0	1160.4	11.93	7.74	93.33	42746.6	2.87	71.28

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
3.0	300.0	100.0	116.02	15.71	.33	5.46	5.79	1550.9	1210.6	7.90	3.95	84.24	32750.8	2.85	70.00
4.0	400.0	100.0	116.00	15.84	.35	6.28	6.62	1577.9	1186.0	8.91	5.26	88.70	38588.4	2.86	70.61
5.0	500.0	100.0	115.98	15.96	.36	7.08	7.44	1595.2	1170.3	9.32	6.57	91.55	44412.9	2.87	71.00
6.0	600.0	100.0	115.96	16.07	.37	7.88	8.25	1607.1	1159.4	10.93	7.88	93.51	50230.2	2.87	71.27
7.0	700.0	100.0	115.95	16.19	.39	8.66	9.05	1615.6	1151.6	11.93	9.19	94.91	56043.1	2.88	71.46

TABLE C-3

CORE HEAT TRANSFER SURFACE	AIR-SIDE	GAS-SIDE
TYPE AND FIN DETAIL	1-0.0000-0-11.10	1-0.0000-0-11.10
PLATE SPACING	.2500 IN	.2500 IN
HYDRAULIC RADIUS	.00253 FT	.00253 FT
FIN THICKNESS	.0060 IN	.0060 IN
COMPACTNESS	367.0 SQFT/CUFT	367.0 SQFT/CUFT
FIN/TOTAL AREA	.7560 FT/FT	.7560 FT/FT

HEAT EXCHANGER CONDITIONS	AIR-SIDE INLET	GAS-SIDE INLET	GAS-SIDE EXIT
MASSFLOW	90.00 LB/SEC	101.75 LB/SEC	-
PRESSURE	223.60 PSIA	-	14.90 PSIA
TEMPERATURE	875.90 DEG R	1426.80 DEG R	-
FUEL-AIR RATIO	0.0	.0175	.0175

HEADER DESIGN DETAILS

INLET AIR HEADER DIAMETER SIZED FOR INLET AIR VELOCITY = 90.00 FT/SEC
OUTLET AIR HEADER DIAMETER SIZED FOR UNIFORM FLOW DISTRIBUTION AND MINIMUM HEADER LOSS
INLET DIAMETER = 1.36 FT
EXIT AIR DIAMETER AND VELOCITY GIVEN BELOW

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
3.0	75.0	25.0	222.71	18.85	.40	26.52	26.92	1287.2	1082.1	6.24	2.41	74.51	7778.6	1.88	69.41
4.0	100.0	25.0	222.66	19.30	.42	29.50	29.92	1320.1	1052.8	7.25	3.21	80.53	9380.6	1.89	70.29
5.0	125.0	25.0	222.60	19.79	.45	32.83	33.28	1342.4	1032.9	8.26	4.01	84.60	10995.4	1.90	70.89
6.0	150.0	25.0	222.54	20.31	.47	36.29	36.76	1358.4	1018.5	9.27	4.80	87.51	12600.5	1.91	71.33
7.0	175.0	25.0	222.49	20.75	.50	39.26	39.76	1370.3	1007.7	10.27	5.60	89.69	14204.4	1.91	71.65

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
3.0	150.0	50.0	223.00	16.43	.27	10.29	10.55	1311.2	1060.8	6.25	2.96	78.90	14596.8	1.89	70.01
4.0	200.0	50.0	222.99	16.69	.28	12.03	12.31	1340.7	1034.4	7.26	3.93	84.29	17638.6	1.90	70.79
5.0	250.0	50.0	222.97	16.94	.28	13.68	13.96	1360.2	1016.9	8.27	4.91	87.84	20674.5	1.91	71.30
6.0	300.0	50.0	222.95	17.17	.29	15.22	15.52	1373.9	1004.5	9.27	5.89	90.35	23707.6	1.91	71.67
7.0	350.0	50.0	222.93	17.40	.30	16.75	17.05	1384.0	995.3	10.28	6.87	92.19	26738.3	1.91	71.94

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
3.0	225.0	75.0	223.10	15.73	.23	5.60	5.82	1321.3	1051.8	6.25	3.24	80.74	21228.6	1.89	70.26
4.0	300.0	75.0	223.08	15.88	.23	6.59	6.82	1349.2	1026.8	7.26	4.32	85.84	25672.5	1.90	70.99
5.0	375.0	75.0	223.07	16.02	.23	7.55	7.78	1367.5	1010.3	8.27	5.39	89.17	30108.7	1.91	71.48
6.0	450.0	75.0	223.06	16.17	.24	8.49	8.73	1380.2	998.8	9.27	6.46	91.50	34540.1	1.91	71.82
7.0	525.0	75.0	223.05	16.30	.24	9.42	9.66	1389.5	990.4	10.28	7.54	93.19	38968.6	1.92	72.06

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
3.0	300.0	100.0	223.13	15.47	.21	3.79	4.04	1335.0	1039.5	6.26	3.71	83.24	27773.3	1.90	70.62
4.0	400.0	100.0	223.12	15.57	.21	4.49	4.70	1360.7	1016.4	7.27	4.94	87.34	33603.0	1.91	71.30
5.0	500.0	100.0	223.12	15.67	.22	5.17	5.39	1377.2	1001.5	8.27	6.18	90.35	39422.5	1.91	71.73
6.0	600.0	100.0	223.11	15.77	.22	5.95	6.07	1388.6	991.2	9.28	7.41	93.02	45236.4	1.92	72.03
7.0	700.0	100.0	223.10	15.87	.22	6.51	6.74	1396.8	983.8	10.28	8.65	94.52	51046.9	1.92	72.24

TABLE C-4

CORE HEAT TRANSFER SURFACE	AIR-SIDE	GAS-SIDE
TYPE AND FIN DETAIL	2- .1875-0-11.10	1-0.0000-0-11.10
PLATE SPACING	.2500 IN	.2500 IN
HYDRAULIC RADIUS	.00253 FT	.00253 FT
FIN THICKNESS	.0060 IN	.0060 IN
COMPACTNESS	367.0 SQFT/CUFT	367.0 SQFT/CUFT
FIN/TOTAL AREA	.7560 FT/FT	.7560 FT/FT

HEAT EXCHANGER CONDITIONS	AIR-SIDE INLET	GAS-SIDE INLET	GAS-SIDE EXIT
MASSFLOW	90.00 LB/SEC	101.75 LB/SEC	-
PRESSURE	223.60 PSIA	-	14.90 PSIA
TEMPERATURE	870.90 DEG R	1426.20 DEG R	-
FUEL-AIR RATIO	0.0	.0175	.0175

HEADER DESIGN DETAILS

INLET AIR HEADER DIAMETER SIZED FOR INLET AIR VELOCITY = 90.00 FT/SEC
OUTLET AIR HEADER DIAMETER SIZED FOR UNIFORM FLOW DISTRIBUTION AND MINIMUM HEADER LOSS
INLET DIAMETER = 1.36 FT
EXIT AIR DIAMETER AND VELOCITY GIVEN AFLOW

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
3.0	75.0	25.0	221.58	18.82	.91	26.32	27.23	1317.4	1055.3	6.25	3.13	80.03	7774.6	1.89	70.40
4.0	100.0	25.0	221.35	19.27	1.00	29.31	30.31	1345.9	1029.7	7.27	4.16	85.24	9380.1	1.90	71.10
5.0	125.0	25.0	221.13	19.80	1.10	32.80	33.99	1364.7	1012.8	8.27	5.20	88.66	10903.1	1.91	71.72
6.0	150.0	25.0	220.91	20.27	1.20	36.05	37.25	1377.8	1001.0	9.28	6.23	91.05	12584.3	1.92	72.10
7.0	175.0	25.0	220.70	20.72	1.30	39.06	40.36	1387.4	992.3	10.28	7.27	92.81	14184.5	1.92	72.39

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
3.0	150.0	50.0	222.55	16.41	.47	10.14	10.61	1343.6	1031.8	6.26	4.06	84.82	14587.0	1.90	70.94
4.0	200.0	50.0	222.48	16.67	.50	11.90	12.40	1367.7	1010.1	7.27	5.40	89.21	17619.0	1.91	71.57
5.0	250.0	50.0	222.41	16.91	.53	13.51	14.05	1382.9	996.3	8.28	6.75	92.00	20646.6	1.91	71.99
6.0	300.0	50.0	222.34	17.15	.56	15.09	15.66	1393.4	986.8	9.28	8.09	93.90	23671.2	1.92	72.28
7.0	350.0	50.0	222.27	17.30	.60	16.62	17.22	1400.8	980.1	10.28	9.44	95.26	26694.1	1.92	72.48

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
3.0	225.0	75.0	222.81	15.72	.35	5.51	5.86	1354.6	1021.9	6.27	4.59	86.82	21213.0	1.90	71.19
4.0	300.0	75.0	222.77	15.87	.37	6.50	6.87	1376.5	1002.2	7.27	6.11	90.81	25642.2	1.91	71.77
5.0	375.0	75.0	222.74	16.01	.39	7.47	7.85	1390.2	989.8	8.28	7.63	93.31	30064.7	1.92	72.13
6.0	450.0	75.0	222.70	16.15	.40	8.42	8.82	1399.4	981.4	9.28	9.14	95.00	34483.5	1.92	72.37
7.0	525.0	75.0	222.66	16.29	.42	9.35	9.77	1405.9	975.4	10.28	10.66	96.19	38900.1	1.92	72.55

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
3.0	300.0	100.0	222.93	15.46	.30	3.74	4.04	1365.0	1012.6	6.27	5.22	88.72	27747.4	1.91	71.44
4.0	400.0	100.0	222.91	15.56	.31	4.43	4.74	1384.7	994.7	7.28	6.94	92.31	33557.4	1.91	71.96
5.0	500.0	100.0	222.88	15.66	.32	5.12	5.44	1396.8	983.7	8.28	8.66	94.53	39359.2	1.92	72.28
6.0	600.0	100.0	222.86	15.76	.33	5.80	6.13	1404.9	976.4	9.28	10.38	96.00	45156.6	1.92	72.49
7.0	700.0	100.0	222.84	15.96	.34	6.47	6.81	1410.5	971.3	10.28	12.11	97.02	50951.5	1.92	72.64

TABLE C-5

CORE HEAT TRANSFER SURFACE		AIR-SIDE	GAS-SIDE	
	TYPE AND FIN DETAIL	2- .1875-0-11.10	1-0.0000-0- 6.20	
	PLATE SPACING	.2500 IN	.4050 IN	
	HYDRAULIC RADIUS	.00253 FT	.00455 FT	
	FIN THICKNESS	.0060 IN	.0100 IN	
	COMPACTNESS	367.0 SQFT/CUFT	204.0 SQFT/CUFT	
	FIN/TOTAL AREA	.7560 FT/FT	.7200 FT/FT	

HEAT EXCHANGER CONDITIONS		AIR-SIDE INLET	GAS-SIDE INLET	GAS-SIDE EXIT
	MASSFLOW	90.00 LB/SEC	101.75 LB/SEC	-
	PRESSURE	223.60 PSIA	-	14.90 PSIA
	TEMPERATURE	870.90 DEG R	1426.00 DEG R	-
	FUEL-AIR RATIO	0.0	.0175	.0175

HEADER DESIGN DETAILS

INLET AIR HEADER DIAMETER SIZED FOR INLET AIR VELOCITY = 90.00 FT/SEC
OUTLET AIR HEADER DIAMETER SIZED FOR UNIFORM FLOW DISTRIBUTION AND MINIMUM HEADER LOSS
INLET DIAMETER = 1.36 FT
EXIT AIR DIAMETER AND VELOCITY GIVEN BELOW

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
4.0	100.0	25.0	220.34	16.53	1.46	10.92	12.37	1285.0	1083.3	7.25	2.38	74.26	9444.2	1.88	69.74
5.0	125.0	25.0	220.00	16.74	1.61	12.36	13.97	[illegible]	1060.2	8.26	2.97	79.01	11063.8	1.89	70.49
6.0	150.0	25.0	219.65	16.95	1.77	13.74	15.51	1331.0	1043.1	9.26	3.56	82.51	12681.6	1.90	71.07
7.0	175.0	25.0	219.31	17.15	1.92	15.09	17.01	1345.7	1029.9	10.27	4.15	85.19	14297.9	1.91	71.52
8.0	200.0	25.0	218.96	17.34	2.07	16.41	18.48	1357.2	1019.5	11.27	4.74	87.31	15913.3	1.91	71.80

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
4.0	200.0	50.0	222.10	15.40	.67	3.38	4.05	1305.6	1065.0	7.25	2.81	77.97	17745.9	1.89	70.00
5.0	250.0	50.0	221.99	15.48	.72	3.88	4.60	1329.7	1044.2	8.26	3.52	82.28	20807.3	1.90	70.65
6.0	300.0	50.0	221.88	15.55	.77	4.38	5.15	1347.2	1028.6	9.26	4.22	85.47	23864.8	1.90	71.13
7.0	350.0	50.0	221.78	15.63	.81	4.88	5.69	1360.3	1016.7	10.27	4.92	87.87	26920.2	1.91	71.58
8.0	400.0	50.0	221.67	15.70	.86	5.37	6.23	1370.6	1007.5	11.27	5.62	89.73	29973.7	1.91	71.79

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
4.0	300.0	75.0	222.55	15.16	.47	1.71	2.19	1311.4	1060.5	7.25	2.96	78.95	25830.7	1.89	70.09
5.0	375.0	75.0	222.49	15.19	.50	1.97	2.47	1334.4	1040.1	8.26	3.69	83.13	30304.6	1.90	70.70
6.0	450.0	75.0	222.43	15.23	.52	2.23	2.75	1351.0	1025.1	9.27	4.40	86.17	34773.0	1.90	71.15
7.0	525.0	75.0	222.38	15.27	.55	2.49	3.04	1363.7	1013.0	10.27	5.13	88.47	39238.1	1.91	71.49
8.0	600.0	75.0	222.32	15.31	.57	2.75	3.32	1373.5	1004.0	11.27	5.86	90.27	43700.0	1.91	71.76

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
4.0	400.0	100.0	222.75	15.08	.38	1.18	1.56	1329.6	1044.3	7.26	3.51	82.26	33821.1	1.90	70.54
5.0	500.0	100.0	222.71	15.10	.40	1.36	1.76	1350.3	1025.0	8.26	4.37	86.04	39690.3	1.90	71.09
6.0	600.0	100.0	222.67	15.13	.41	1.54	1.96	1365.1	1012.4	9.27	5.23	88.74	45552.9	1.91	71.49
7.0	700.0	100.0	222.64	15.16	.43	1.73	2.16	1376.2	1002.4	10.27	6.09	90.77	51411.3	1.91	71.78
8.0	800.0	100.0	222.60	15.18	.45	1.91	2.36	1384.7	994.7	11.28	6.95	92.32	57267.0	1.91	72.01

TABLE C-6

CORE HEAT TRANSFER SURFACE	AIR-SIDE	GAS-SIDE
TYPE AND FIN DETAIL	1-0.0000-0-19.86	1-0.0000-0-11.10
PLATE SPACING	.2500 IN	.2500 IN
HYDRAULIC RADIUS	.00154 FT	.00253 FT
FIN THICKNESS	.0060 IN	.0060 IN
COMPACTNESS	561.0 SQFT/CUFT	367.0 SQFT/CUFT
FIN/TOTAL AREA	.6490 FT/FT	.7560 FT/FT

HEAT EXCHANGER CONDITIONS	AIR-SIDE INLET	GAS-SIDE INLET	GAS-SIDE EXIT
MASSFLOW	90.00 LB/SEC	101.75 LB/SEC	-
PRESSURE	223.60 PSIA	-	14.90 PSIA
TEMPERATURE	876.90 DEG R	1426.80 DEG R	-
FUEL-AIR RATIO	0.0	.0175	.0175

HEADER DESIGN DETAILS

INLET AIR HEADER DIAMETER SIZED FOR INLET AIR VELOCITY = 90.00 FT/SEC
OUTLET AIR HEADER DIAMETER SIZED FOR UNIFORM FLOW DISTRIBUTION AND MINIMUM HEADER LOSS
INLET DIAMETER = 1.36 FT
EXIT AIR DIAMETER AND VELOCITY GIVEN BELOW

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
2.0	50.0	25.0	222.38	18.25	.55	22.50	23.04	1263.0	1103.4	5.23	2.00	70.11	7207.7	1.87	68.81
3.0	75.0	25.0	222.26	18.73	.60	25.71	26.31	1312.2	1059.9	6.25	2.98	79.38	9118.0	1.89	70.15
4.0	100.0	25.0	222.15	19.26	.65	29.26	29.91	1341.5	1033.7	7.26	3.97	84.43	11022.9	1.90	70.94
5.0	125.0	25.0	222.03	19.81	.70	32.93	33.63	1360.8	1016.3	8.27	4.95	87.96	12924.0	1.91	71.40
6.0	150.0	25.0	221.91	20.28	.75	36.08	36.84	1374.5	1004.0	9.27	5.94	90.45	14823.0	1.91	71.85

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
2.0	100.0	50.0	222.83	16.16	.35	9.48	8.83	1293.8	1076.3	5.24	2.54	75.72	13665.0	1.88	69.57
3.0	150.0	50.0	222.78	16.42	.37	10.22	10.59	1337.6	1037.2	6.26	3.81	83.73	17307.5	1.90	70.74
4.0	200.0	50.0	222.74	16.68	.39	11.92	12.31	1362.8	1014.5	7.27	5.07	88.32	20937.1	1.91	71.40
5.0	250.0	50.0	222.69	16.92	.41	13.54	13.94	1378.9	1000.0	8.27	6.34	91.26	24561.2	1.91	71.84
6.0	300.0	50.0	222.65	17.15	.42	15.11	15.54	1390.0	989.9	9.28	7.60	93.28	28181.7	1.92	72.14

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
2.0	150.0	75.0	222.93	15.57	.30	4.53	4.83	1313.5	1058.7	5.25	3.02	79.32	19972.7	1.89	70.88
3.0	225.0	75.0	222.90	15.72	.31	5.52	5.83	1351.2	1023.2	6.26	4.52	86.56	25314.6	1.90	71.13
4.0	300.0	75.0	222.87	15.87	.32	6.50	6.83	1375.4	1003.2	7.27	6.01	90.61	30639.5	1.91	71.72
5.0	375.0	75.0	222.85	16.01	.34	7.47	7.81	1389.3	990.5	8.28	7.51	93.15	35956.1	1.92	72.09
6.0	450.0	75.0	222.82	16.15	.35	8.42	8.77	1398.7	982.0	9.28	9.01	94.87	41268.2	1.92	72.33

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
2.0	200.0	100.0	222.99	15.35	.27	3.04	3.32	1330.5	1043.5	5.26	3.54	82.42	26207.9	1.90	70.52
3.0	300.0	100.0	222.97	15.46	.28	3.74	4.02	1366.2	1011.5	6.27	5.30	88.93	33231.2	1.91	71.45
4.0	400.0	100.0	222.95	15.56	.29	4.43	4.72	1385.6	933.9	7.28	7.05	92.48	40234.6	1.91	71.98
5.0	500.0	100.0	222.92	15.66	.30	5.12	5.42	1397.6	983.0	8.28	8.80	94.67	47227.7	1.92	72.29
6.0	600.0	100.0	222.90	15.76	.31	5.90	6.11	1405.5	975.8	9.28	10.55	96.11	54215.8	1.92	72.50

TABLE C-7

CORE HEAT TRANSFER SURFACE	AIR-SIDE	GAS-SIDE
TYPE AND FIN DETAIL	1-0.0000-0- 6.20	1-0.0000-0- 3.01
PLATE SPACING	.4050 IN	.7500 IN
HYDRAULIC RADIUS	.00455 FT	.00887 FT
FIN THICKNESS	.0100 IN	.0320 IN
COMPACTNESS	204.0 SQFT/CUFT	94.3 SQFT/CUFT
FIN/TOTAL AREA	.7280 FT/FT	.7060 FT/FT

HEAT EXCHANGER CONDITIONS	AIR-SIDE INLET	GAS-SIDE INLET	GAS-SIDE EXIT
MASSFLOW	90.00 LB/SEC	101.75 LB/SEC	-
PRESSURE	223.60 PSIA	-	14.90 PSIA
TEMPERATURE	874.90 DEG R	1426.80 DEG R	-
FUEL-AIR RATIO	0.0	.0175	.0175

HEADER DESIGN DETAILS

INLET AIR HEADER DIAMETER SIZED FOR INLET AIR VELOCITY = 90.00 FT/SEC
OUTLET AIR HEADER DIAMETER SIZED FOR UNIFORM FLOW DISTRIBUTION AND MINIMUM HEADER LOSS
INLET DIAMETER = 1.36 FT
EXIT AIR DIAMETER AND VELOCITY GIVEN BELOW

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
14.0	350.0	25.0	222.25	16.88	.68	13.31	13.91	1324.4	1049.0	17.26	3.34	81.31	30294.1	1.89	70.40
15.0	375.0	25.0	222.21	16.98	.62	13.95	14.57	1331.4	1042.7	18.26	3.58	82.59	32212.3	1.90	70.67
16.0	400.0	25.0	222.16	17.07	.64	14.59	15.23	1337.7	1037.1	19.26	3.81	83.74	34130.3	1.90	70.84
17.0	425.0	25.0	222.12	17.17	.66	15.22	15.88	1343.4	1032.0	20.26	4.05	84.78	36048.1	1.90	71.00
18.0	450.0	25.0	222.08	17.26	.68	15.85	16.53	1348.6	1027.3	21.26	4.28	85.72	37965.8	1.90	71.15
19.0	475.0	25.0	222.03	17.35	.70	16.46	17.16	1353.3	1023.1	22.27	4.52	86.58	39883.2	1.91	71.28
20.0	500.0	25.0	221.99	17.44	.72	17.07	17.79	1357.6	1019.2	23.27	4.76	87.36	41900.6	1.91	71.40
21.0	525.0	25.0	221.95	17.53	.74	17.67	18.41	1361.5	1015.7	24.27	4.99	88.09	43717.8	1.91	71.51

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
14.0	700.0	50.0	222.88	15.56	.32	4.46	4.78	1344.7	1030.8	17.26	4.11	85.02	57723.5	1.90	70.92
15.0	750.0	50.0	222.87	15.60	.33	4.71	5.04	1350.9	1025.3	18.26	4.40	86.14	61383.6	1.90	71.08
16.0	800.0	50.0	222.86	15.64	.33	4.96	5.29	1356.4	1020.3	19.27	4.69	87.14	65043.3	1.90	71.23
17.0	850.0	50.0	222.85	15.68	.34	5.20	5.54	1361.3	1015.9	20.27	4.98	88.04	68702.5	1.91	71.36
18.0	900.0	50.0	222.83	15.71	.34	5.45	5.79	1365.8	1011.9	21.27	5.27	88.86	72361.5	1.91	71.48
19.0	950.0	50.0	222.82	15.75	.35	5.69	6.04	1369.8	1008.2	22.27	5.56	89.59	76020.2	1.91	71.58
20.0	1000.0	50.0	222.81	15.78	.35	5.93	6.29	1373.5	1004.9	23.27	5.85	90.27	79678.6	1.91	71.68
21.0	1050.0	50.0	222.80	15.82	.36	6.17	6.53	1376.8	1001.9	24.27	6.14	90.88	83336.8	1.91	71.77

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
14.0	1050.0	75.0	223.04	15.26	.25	2.40	2.65	1351.3	1024.8	17.26	4.42	86.23	84646.4	1.90	71.07
15.0	1125.0	75.0	223.03	15.28	.25	2.54	2.79	1357.2	1019.6	18.27	4.73	87.29	90019.3	1.90	71.22
16.0	1200.0	75.0	223.03	15.30	.26	2.68	2.93	1362.4	1014.9	19.27	5.05	88.25	95391.7	1.91	71.36
17.0	1275.0	75.0	223.02	15.32	.26	2.81	3.07	1367.1	1010.7	20.27	5.36	89.10	100763.4	1.91	71.48
18.0	1350.0	75.0	223.01	15.34	.26	2.95	3.21	1371.3	1006.9	21.27	5.68	89.87	106134.8	1.91	71.59
19.0	1425.0	75.0	223.01	15.36	.26	3.09	3.35	1375.1	1003.4	22.27	5.99	90.56	111505.7	1.91	71.69
20.0	1500.0	75.0	223.00	15.38	.27	3.22	3.49	1378.6	1000.3	23.27	6.30	91.19	116876.3	1.91	71.78
21.0	1575.0	75.0	223.00	15.40	.27	3.36	3.63	1381.7	997.4	24.27	6.62	91.77	122246.6	1.91	71.87

TABLE C-8

CORE HEAT TRANSFER SURFACE	AIR-SIDE	GAS-SIDE
TYPE AND FIN DETAIL	3- .1250-0-19.82	3- .2500-0-11.10
PLATE SPACING	.2050 IN	.2500 IN
HYDRAULIC RADIUS	.00127 FT	.00253 FT
FIN THICKNESS	.0040 IN	.0060 IN
COMPACTNESS	680.0 SQFT/CUFT	367.0 SQFT/CUFT
FIN/TOTAL AREA	.8410 FT/FT	.7560 FT/FT

HEAT EXCHANGER CONDITIONS	AIR-SIDE INLET	GAS-SIDE INLET	GAS-SIDE EXIT
MASSFLOW	90.00 LB/SEC	101.75 LB/SEC	-
PRESSURE	223.60 PSIA	-	14.90 PSIA
TEMPERATURE	870.90 DEG R	1426.00 DEG R	-
FUEL-AIR RATIO	0.0	.0175	.0175

HEADER DESIGN DETAILS

INLET AIR HEADER DIAMETER SIZED FOR INLET AIR VELOCITY = 90.00 FT/SEC
OUTLET AIR HEADER DIAMETER SIZED FOR UNIFORM FLOW DISTRIBUTION AND MINIMUM HEADER LOSS
INLET DIAMETER = 1.36 FT
EXIT AIR DIAMETER AND VELOCITY GIVEN BELOW

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
1.0	25.0	25.0	219.47	19.24	1.85	29.13	30.98	1250.8	1114.1	4.24	1.82	67.68	5457.4	1.87	68.92
2.0	50.0	25.0	218.72	20.07	2.18	34.68	36.86	1332.4	1041.8	5.27	3.61	82.78	7437.8	1.90	71.26
3.0	75.0	25.0	218.00	20.76	2.50	39.35	41.85	1367.6	1010.2	6.28	5.40	89.20	9401.6	1.92	72.29
4.0	100.0	25.0	217.30	21.70	2.82	45.64	48.46	1386.7	992.9	7.29	7.18	92.69	11360.6	1.93	72.93
5.0	125.0	25.0	216.60	22.40	3.13	50.33	53.46	1398.5	982.2	8.29	8.97	94.83	13316.8	1.93	73.36
6.0	150.0	25.0	215.90	23.07	3.45	54.83	58.28	1406.2	975.1	9.30	10.75	96.25	15271.8	1.94	73.68
7.0	175.0	25.0	215.20	23.70	3.76	59.03	62.79	1411.6	970.3	10.30	12.54	97.22	17226.1	1.94	73.94
8.0	200.0	25.0	214.50	24.29	4.07	62.99	67.06	1415.4	966.8	11.30	14.32	97.92	19179.8	1.94	74.16

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
1.0	50.0	50.0	221.62	16.54	.89	11.02	11.91	1296.4	1073.9	4.25	2.60	76.20	10349.7	1.89	69.83
2.0	100.0	50.0	221.37	16.99	1.00	14.06	15.06	1364.2	1013.2	5.27	5.17	88.58	14123.1	1.91	71.67
3.0	150.0	50.0	221.15	17.42	1.10	16.80	17.90	1390.9	989.1	6.28	7.73	93.45	17867.5	1.92	72.39
4.0	200.0	50.0	220.93	17.83	1.19	19.64	20.84	1404.5	976.7	7.29	10.29	95.93	21604.1	1.93	72.79
5.0	250.0	50.0	220.72	18.21	1.29	22.23	23.52	1412.3	969.6	8.29	12.85	97.36	25336.5	1.93	73.03
6.0	300.0	50.0	220.51	18.58	1.38	24.69	26.07	1417.2	965.1	9.29	15.41	98.25	29067.8	1.93	73.19
7.0	350.0	50.0	220.29	18.95	1.48	27.20	28.68	1420.3	962.3	10.29	17.97	98.81	32796.0	1.93	73.30
8.0	400.0	50.0	220.08	19.30	1.57	29.52	31.09	1422.4	960.4	11.29	20.53	99.19	36524.7	1.93	73.39

LENGTH FT	VOLUME CU FT	AREA SQFT	P-A-EX PSIA	P-G-IN PSIA	DPA PCT	DPG PCT	DPT PCT	T-A-EX DEG R	T-G-EX DEG R	HEIGHT FT	NTU	EFFECT PCT	WEIGHT LBS	HEADER DIA FT	VELOCITY FT/SEC
1.0	75.0	75.0	222.18	15.86	.63	6.42	7.05	1319.8	1053.1	4.25	3.20	80.47	15120.7	1.89	70.36
2.0	150.0	75.0	222.05	16.14	.69	8.30	8.99	1379.2	999.7	5.28	6.36	91.31	20853.6	1.91	71.95
3.0	225.0	75.0	221.93	16.42	.75	10.18	10.93	1401.2	979.7	6.28	9.52	95.33	26148.1	1.92	72.53
4.0	300.0	75.0	221.81	16.66	.80	11.97	12.77	1411.9	969.9	7.29	12.68	97.29	31632.6	1.93	72.84
5.0	375.0	75.0	221.70	16.95	.85	13.75	14.60	1417.8	964.5	8.29	15.84	98.36	37111.3	1.93	73.00
6.0	450.0	75.0	221.58	17.20	.90	15.44	16.34	1421.2	961.4	9.29	19.01	98.98	42588.3	1.93	73.11
7.0	525.0	75.0	221.47	17.44	.95	17.08	18.03	1423.3	959.5	10.29	22.17	99.36	48064.0	1.93	73.18
8.0	600.0	75.0	221.36	17.68	1.00	18.66	19.66	1424.6	958.3	11.29	25.33	99.60	53538.9	1.93	73.24

DTNSRDC PAS 82-41 ATTACHMENT A

KEY TO AIR-SIDE OR GAS-SIDE FIN GEOMETRIES*

PLAIN FINS (TYPA/G = 1)

NSA/G	FINS/IN	PLATE SPACING, IN
1	2.00	0.750
2	3.01	0.750
3	3.97	0.750
4	5.30	0.470
5	6.20	0.405
6	9.03	0.823
7	11.10	0.250
8	11.11	0.480
9	14.77	0.330
10	15.08	0.418
11	19.86	0.250
12	10.27	0.544
13	11.94	0.249
14	12.00	0.250
15	16.96	0.256
16	25.79	0.204
17	30.33	0.345
18	46.45	0.100

LOUVERED FINS (TYPA/G = 2)

NSA/G	FINS/IN	PLATE SPACING, IN	LOUVER SPACING, IN	LOUVER GAP, IN
1	6.06	0.250	0.375	0.055
2	6.06	0.250	0.375	0.130
3	6.06	0.250	0.500	0.055
4	6.06	0.250	0.500	0.130
5	8.70	0.250	0.375	0.055
6	8.70	0.250	0.375	0.080
7	11.10	0.250	0.1875	0.055
8	11.10	0.250	0.250	0.035
9	11.10	0.250	0.250	0.055
10	11.10	0.250	0.375	0.055
11	11.10	0.250	0.375	0.055
12	11.10	0.250	0.500	0.055
13	11.10	0.250	0.750	0.040
14	11.10	0.250	0.750	0.040

STRIP/OFFSET FINS (TYPA/G = 3)

NSA/G	FINS/IN	PLATE SPACING, IN
1	11.10	0.250
2	12.20	0.485
3	15.20	0.414
4	13.95	0.375
5	11.94	0.237
6	15.40	0.206
7	12.18	0.353
8	15.75	0.304
9	20.06	0.201
10	19.82	0.205
11	16.12	0.206
12	16.00	0.255

WAVY FINS (TYPA/G = 4)

NSA/G	FINS/IN	PLATE SPACING, IN
1	11.44	0.413
2	11.50	0.375
3	17.80	0.413

* From Tables 9-3 (a), (b), (c) and (d) in Kay's and London "Compact Heat Exchangers."

DTNSRDC ISSUES THREE TYPES OF REPORTS

1. DTNSRDC REPORTS, A FORMAL SERIES, CONTAIN INFORMATION OF PERMANENT TECHNICAL VALUE. THEY CARRY A CONSECUTIVE NUMERICAL IDENTIFICATION REGARDLESS OF THEIR CLASSIFICATION OR THE ORIGINATING DEPARTMENT.

2. DEPARTMENTAL REPORTS, A SEMIFORMAL SERIES, CONTAIN INFORMATION OF A PRELIMINARY, TEMPORARY, OR PROPRIETARY NATURE OR OF LIMITED INTEREST OR SIGNIFICANCE. THEY CARRY A DEPARTMENTAL ALPHANUMERICAL IDENTIFICATION.

3. TECHNICAL MEMORANDA, AN INFORMAL SERIES, CONTAIN TECHNICAL DOCUMENTATION OF LIMITED USE AND INTEREST. THEY ARE PRIMARILY WORKING PAPERS INTENDED FOR INTERNAL USE. THEY CARRY AN IDENTIFYING NUMBER WHICH INDICATES THEIR TYPE AND THE NUMERICAL CODE OF THE ORIGINATING DEPARTMENT. ANY DISTRIBUTION OUTSIDE DTNSRDC MUST BE APPROVED BY THE HEAD OF THE ORIGINATING DEPARTMENT ON A CASE-BY-CASE BASIS.